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OLD DOMINION UNIVERSITY

DEPARTMENT of MECHANICAL ENGINEERING and MECHANICS

1992-3 ADVANCED DESIGN PROGRAM

FINAL REPORT

Part 1 - The Mars Methane Engine Project

Part 2 - The Mars Oxygen Processor New Furnace

(NASA-CR-195513) THE 1992-1993 ADVANCED DESIGN PROGRAM. PART 1: THE MARS METHANE ENGINE PROJECT. PART 2: THE MARS OXYGEN PROCESSOR NEW FURNACE Final Report (Old Dominion Univ.) 173 p

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MARS METHANE ENGINE

Senior Design Project
MEM 434
Final Report

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ABSTRACT

Three constituents of the Martian atmosphere: methane, carbon dioxide, and oxygen, can be used for internal combustion in engines utilized for future space exploration on Mars. These three gases, considered as the test case in this research, will be examined to determine required flowrates needed for combustion and optimization of engine performance. Results of the test case are examined in relation to a base case of methane and air for comparative purposes. Modification of a single cylinder Honda engine, as well as programming of a data acquisition system was required prior to testing. Testing of exhaust temperatures, cylinder pressure and exhaust gas analysis were performed for the base case and test case.

1. INTRODUCTION

An important aspect of technological advancements in space exploration involves the utilization of existing equipment and machinery along with the constraints of the atmosphere under consideration. One example of this combination is internal combustion engines on the planet Mars. As missions to Mars advance, it will be desired to operate internal combustion engines for uses such as generators and operating small machinery. The options of transporting fuel or utilizing the Martian atmosphere for combustion have been investigated and the latter case has been accepted and considered feasible.

The Martian atmosphere contains approximately 95 percent carbon dioxide which can be synthesized with water to produce methane. In addition, oxygen can also be obtained from carbon dioxide by thermal decomposition. The ultimate goal of this project is to effectively operate and obtain results from an internal combustion engine operating on methane, carbon dioxide and oxygen. These three constituents will compose the test case in the experiment. Prior to testing of the three gases, a base case of methane and air was examined for comparative results.

It was the entire design team's motivation as mechanical engineering students within the power/energy option to continue with the work of previous teams and to successfully obtain results from engine operation on both the base case and test case. The objectives, planning, research, testing and results, future work plans, and conclusions are now discussed in detail.

2. OBJECTIVES

The Mars methane engine project has been an ongoing project for the past few years. Previous design teams had experienced many difficulties in their work and were not able to obtain any substantial test results. However, due to several major changes and advancements, this semester has marked a turning point for the project. In particular, the main problem encountered by last semester's team was the internal combustion engine being used. A one-cylinder Megatech lab engine was used and was not able to perform adequately under operating conditions. The higher temperatures resulting from the combustion of methane and poor tolerances in the cylinder caused fracture of the cylinder. The team designed and machined a stainless steel cylinder but still experienced difficulties. Actual combustion of the base case and test case was achieved but no data was collected.

After facing these problems, the team decided to research all other aspects of the project including purchasing a new engine and ordering and receiving all equipment needed. It was our goal to make use of the equipment and instrumentation provided, complete the entire setup of the project, and obtain some preliminary results of both the base case and test case. This would then allow future design teams to concentrate entirely on testing and optimization of performance.

Once the entire setup was complete, the intent was to perform testing of the base case and test case to draw conclusions on the comparison of the cases and the optimization of performance. The entire setup of the project involved constructing a mounting stand, performing all necessary engine modifications, connecting the engine to the dynamometer and installing the data acquisition system. Upon completion of setup and all required testing, it was then desired to interpret the comparative date into tabular and graphical form to draw conclusions. Such performance criteria as pressure versus volume and horsepower versus specific fuel consumption would provide conclusions to the optimization of engine operation.

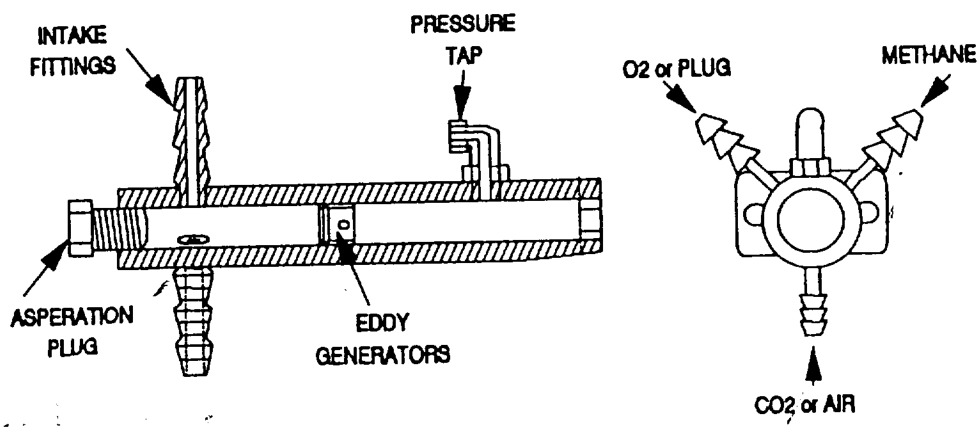
3. PLAN

As stated earlier, all major equipment and instrumentation needed for the project was researched and obtained by the previous design team. This includes: 1) a new Honda GX120 4Hp engine, 2) an AVL 8QP500C pressure transducer, 3) an AVL charge amplifier, 4) three Cole Parmer variable area flowmeters, 5) a Lucas Ledex K3 Series incremental encoder, and 6) an Omega K type thermocouple. The new engine required a larger dynamometer which was readily available in the thermodynamics laboratory. Each of these is discussed in detail within the report.

In general, our team planned to review all work, make all necessary modifications to the engine, complete the system setup, and begin preliminary testing. A more detailed listing of these procedures can be found in the Gantt chart in Appendix A. Although most work was performed on a group basis, each member was assigned to a particular area of concentration. These areas are the installation of the pressure transducer, stoichiometries and flowrates for combustion, data acquisition, and instrumentation.

4. ENGINE MODIFICATIONS

In operating the engine on methane, carbon dioxide, and oxygen, the existing air-fuel carburetor, throttling mechanism, and fuel system must be removed. Since the required fuels are supplied by pressurized tanks and controlled by flowmeters, it was not necessary to incorporate a mixing chamber into the setup. This mixing chamber, shown below, was manufactured by last semester's team and was adapted to the new engine.



The mixing chamber has eddy generators to promote mixing and turbulent conditions. This has been confirmed by previous team calculations. A pressure gage was connected to the tap in the mixing chamber to monitor inlet pressures for testing. A drawing of the adaptor that was needed to install the mixing chamber onto the Honda engine is shown in Appendix B.

The engine also needed modifications to both ends of the shaft. A fitting was installed to the end of the shaft connected to the dynamometer. The other end was also adapted for connection with the incremental encoder. These modifications are shown in Appendix C.

It is required that both exhaust samples and temperature reading be taken at the exhaust outlet of the engine. For this reason, an exhaust extension was designed and machined. This extension also relocated the muffler allowing more access to the engine head for the pressure transducer to be mounted. The extension provides the space necessary to install the thermocouple and exhaust gas sample cylinder. The team had initially decided to mount these instruments directly into the muffler but realized that an extension would provide more accurate results and less damage to the existing engine. With the use of the extension, temperature readings are able to be taken in the direct vicinity of the exhaust port. Appendix D shows the extension.

Finally, the most important modification made to the engine was the installation of the pressure transducer. This was a difficult process that required a great deal of consideration and precise measurements. The pressure transducer was mounted onto the cylinder head to measure pressure in the combustion chamber at particular cylinder positions. In determining the location of the transducer in the cylinder head, three suggested criteria were recommended:

1. If possible, at least 50% of the diaphragm surface area should lie over the combustion chamber.
2. The measuring position should not lie in the immediate vicinity of the exhaust valve.
3. Installation of the pressure transducer should be as perpendicular as possible to the cylinder head face and a safety clearance of at least 0.5 mm should be applied.

The limited space within the combustion chamber greatly reduced the ability to adequately meet all three criteria. Approximately 60% of the diaphragm surface area lies directly over the chamber, the location is in the general vicinity of the exhaust valves, and the transducer is mounted at an approximate angle of 30 degrees (See Appendix E). More information on the pressure transducer can be found in Section 6.

5. PROJECT SETUP

The overall setup of the system is shown in Appendix F. A mounting stand was constructed to secure the dynamometer, engine, and encoder. A 12V battery was used to supply DC power to the dynamometer and to start the engine. While testing, it was necessary to water-cool the pressure transducer. It was recommended that a distilled water cooling system be used to reduce these extreme operating temperatures. Due to time limitations and the minimal amount of use of the transducer in this semester's project, a simple open loop water cooling system was connected from a water supply line in the laboratory. The instrumentation (thermocouple, pressure transducer, and incremental encoder) are connected to the data acquisition system via an analog and digital input/output board. This board is a DT2811 provided by Data Translation and a drawing of the assembly and location of the three instruments is shown in Appendix G.

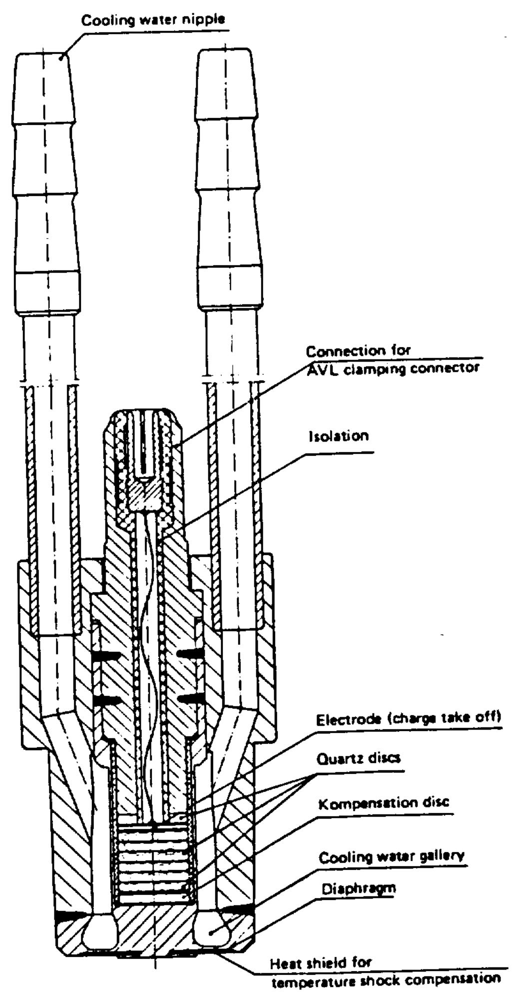
6. RESEARCH

COMBUSTION ANALYSIS

In order to determine the chemically correct mixture of methane, carbon dioxide, and oxygen required for the single cylinder four-stroke Honda engine, many thermodynamic calculations must be made. To begin with, several assumptions must be made for the combustion process. Some of the assumptions are steady flow of the mixture, ideal complete combustion, and adiabatic conditions. From these assumptions and mathematical manipulations, a chemically correct combustion equation can be derived. However, the stoichiometric coefficients of the combustion equation will be found under experimental applications. With the help of these procedures and additional calculations, the appropriate number of combustion products will be determined. Thus, the proper chemical mixture of the fuel can be injected to obtain complete combustion. The preliminary calculations are illustrated in Appendix H.

PRESSURE TRANSDUCER AND CHARGE AMPLIFIER

The AVL 8QP500C pressure transducer utilizes the piezoelectric effect for measuring pressure. The effect involves the use of quartz crystal, effected by a pressure disturbance, to act upon a water-cooled diaphragm and a stiff intermediate element. The pressure transducer is shown below:

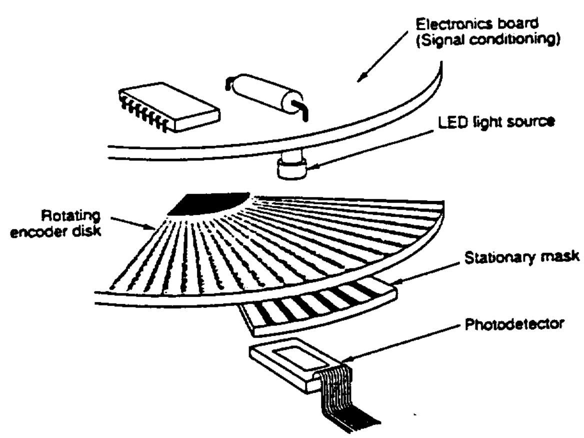


The crystal transforms a pressure signal into an electric charge signal. This electric charge signal is then fed through a coaxial cable (with high impedance isolation) to a charge amplifier where it is then transformed into an electric voltage signal. This signal is then fed through the data acquisition system to provide output.

The charge amplifier chosen is model 3057-A01. It is setup for measurement by means of a digital input (4 digits) for the sensitivity of the transducer, and selection of a measuring range. The length of the piezoelectric transducer connection cable and it's related concern of capacitance have no effect on the accuracy of pressure readings. A drawing of the charge amplifier is shown in Appendix J along with a brief description of some of the key features of the amplifier. In relation to the pressure transducer, it was necessary to machine a bolt to be used in place of the transducer when not in use along with a 12 mm spanner socket for installing the transducer to a recommended torque of 15 Nm.

INCREMENTAL ENCODER

To establish the angular position as a function of time, the team will be using an incremental encoder to generate data. The encoder that was previously chosen is a K3 Series Modular Rotating Encoder. The rotary encoder will convert angular motion into a digital output format that will be interfaced with the data acquisition system. As the encoder disk rotates in front of a stationary mask, it shutters the light from the LED light source. The light is received by a photodetector which produces pulses in the form of a quasi-sine wave output. This sine wave will be converted by the encoder's electronics to a square wave form. Since the encoder that was previously chosen gives a line driver output, the team will use a line driver receiver to transmit the data to the data acquisition system. This encoder also includes a single marker that provides one pulse every 360 degrees of mechanical rotation. This pulse is a reference to determine a home-base position. A drawing of the components of the encoder is shown below.



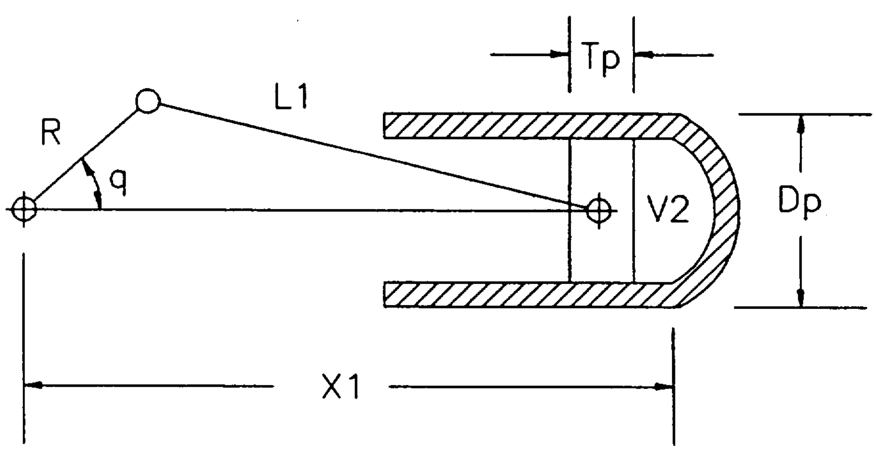
More information on the electrical connections of the encoder can be found in Appendix K.

VOLUME AS A FUNCTION OF CRANK ANGLE

A pressure-volume diagram provides insight into the analysis of internal combustion engine cycles. This pressure-volume relationship can be traced as the crank arm rotates through one complete revolution, moving the piston from top-dead center to bottom-dead center then back again to top-dead center.

In determining volume as a function of angle, two components of the data acquisition system were utilized. First the pressure transducer, mentioned previously in the text, was used in conjunction with the DA system to establish cylinder pressure as a function of time. Over the same time interval an incremental encoder translated the angular position of the piston as a function of time to the DA system in the form of digital output. Combining these two pieces of data yields a relationship between pressure and volume.

The swept volume of fuel in the piston as a function of crank angle can be calculated empirically using the following general formula:



$$V_2 = \frac{\pi D_p^2}{4}\,[X_1 - T_p - R\cos(q) - L_1 \cos[\sin^{-1}[(\frac{R}{L_1})\ \sin(q)]]]$$

A more detailed description of the previous variables, along with all assumptions and calculations is provided in Appendix L. A Fortran computer program is also attached with the volume of the piston for every 3.6 degree revolution of the crank arm.

THERMOCOUPLE

By placing a thermocouple as close to the exhaust outlet as possible, a fairly accurate measurement of the temperature in the combustion chamber could be obtained. The previous team had purchased a type K chromel-alumel thermocouple with inconel sheath. The decided location of the thermocouple is shown in Appendix D. During testing, some difficulty was encountered in measuring the steady state temperatures of the exhaust. This error was traced to the improper channel connection of the thermocouple with the DT2811 hardware board. If not connected to the proper channel, a second cold-junction thermocouple of the same type is formed. This second cold junction will result in measurement errors. This error was corrected by switching the thermocouple connection to channel 4 (See Appendix G).

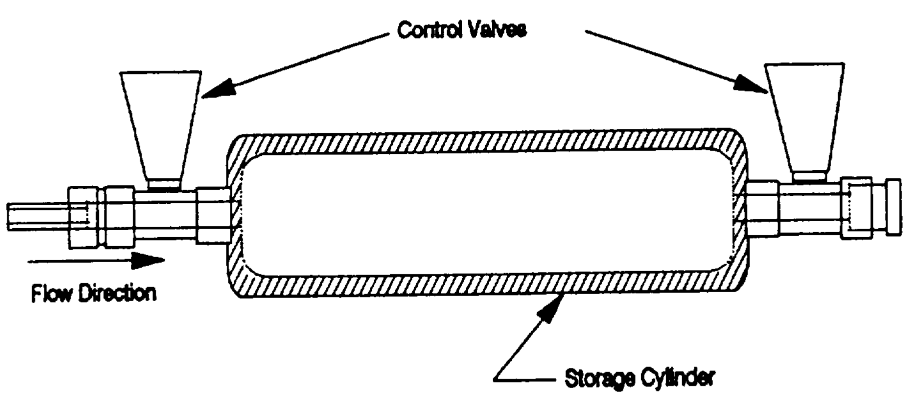
EXHAUST GAS ANALYSIS

An important segment in the testing phase of the project involves the analysis of exhaust samples. This allows for the detection of unburned fuel in the products on a percent concentration basis and gives insight to the reactant flowrate adjustments required for an ideal stoichiometric combustion reaction.

It was suggested by last semester's team and previous members of the Mars Oxygen Processor team that contact be made with Dr. Kennith G. Brown of the Old Dominion University Chemistry Department. Dr. Brown would have the samples analyzed and provide an explanation of the results obtained.

Although the majority of the teams time was consumed producing a functional engine testing assembly, time did permit for the analysis of one exhaust sample from a methane and air mixture. An additional sample of this base case, as well as one sample of the test case of methane, carbon dioxide and oxygen, was also submitted to Dr. Brown. Unfortunately, time did not allow for the analysis process to be completed prior to this report.

As stated in Section 4, a hole was drilled into the machined muffler extension to allow for the samples to be taken. The sample cylinder, shown below, has valves on both ends and rests on a mounting stand during testing.



The valve on the inlet side is connected to copper tubing which is inserted into the muffler extension hole. The outlet valve is connected by clear tubing to a vacuum pump. Exhaust sampling procedures are as follows:

1. Attach vacuum pump to outlet valve and copper tubing to inlet valve.
2. Insert setup into muffler extension shaft.
3. Using vacuum pump, vacuum cylinder for approximately 1 minute. (inlet valve open, outlet valve closed)
4. Once chamber is vacuumed, close outlet valve and prepare engine for sampling.
5. Open inlet valve, followed shortly by opening of the outlet valve.
6. Allow engine to operate for approximately 3-5 minutes observing grey coloration in clear tubing assuring proper flow.
7. Close outlet valve, followed by closing of the inlet valve.

Upon completion of sampling, the cylinder is then analyzed using gas chromatography. This method was chosen because of the negligible cost to the project. The accuracy of this method is also relatively high but the analysis procedures require one to two weeks. Gas chromatography involves the use of the thermal conductance properties of the gases to determine their concentrations. Helium is used as the medium. Two flows, one of pure helium and one of a helium/exhaust gas mixture pass through a gas chromatograph column consisting of a packing material. The gases will pass through the GC column at different speeds for a given temperature. Voltage differences are used to measure the signal intensities for the exhaust sample components that are plotted against the time required for each gas to pass through. Certain peaks coincide with gases, so the products can be determined. This is accomplished by a computer program that also measures the area under each curve. The areas are then used to determine the percent concentration of each product on a 100 percent basis.

As stated earlier, an actual sample of the base case was analyzed by Dr. Brown using the

Gas Chromatography method (See Appendix M for results) These results include peak values, areas and concentrations analyzed by the computer program. The graph of signal intensities versus time is also included. Analysis showed that the CH_4 value determined was inaccurate because of interference with the tailing H_2O peak. It was suggested that a drying tube be placed in-line before the sample bottle; however, the amount of error from this was said to have little impact on altering the current concentration values.

The ideal benefit from this analysis is to compare concentrations of products against those for an ideal, complete stoichiometric combustion equation. The presence of unburned methane or oxygen in the $CH_4/CO_2/O_2$ fuel case would indicate the need to alter the flowrates for optimization.

DATA ACQUISITION

The software used in conjunction with the project is LPCLAB by Data Translation. The software consists of numerous subroutines that can be programmed in various languages for analyzing the data. Prior use of the software by the University has been programmed solely in BASIC. However, each team member is familiar with FORTRAN and MS-Fortran was installed on the system.

LPCLAB facilitates analog-to-digital conversions, digital-to-analog conversions, and digital input/output operations. Testing will require three measurements to be taken by the system: 1) exhaust temperature, 2) cylinder pressure and 3) shaft angle. These measurements can be received by the computer's hardware board and then translated to the appropriate digital or analog signal with the aid of a FORTRAN program.

The FORTRAN program, 'MARS' (Appendix N), has been installed on the computers hard drive. There are three main subroutines that allow for the above measurements to be computed. The first subroutine involves the temperature of the thermocouple. LPMT, LP MEASURE THERMOCOUPLE, calculates the temperature, in degrees Celsius, of a thermocouple of various types. The channel that the thermocouple has been connected to, must be specified in the parameter definitions.

The next subroutine for the pressure transducer is slightly more complicated. The pressure transducer, as explained previously, sends a analog signal to a charge amplifier. This charge amplifier boost the signal, however; the signal remains in an analog form. Therefore, an analog to digital conversion must be installed. LPBAD, LP BURST ANALOG TO DIGITAL, subroutine performs the necessary analog to digital conversions for a specified number of values and stores the resulting data in an analog data array. The operation is complete when LPBAD performs the specific number of values conversions and writes each resulting values to the analog data array. The LPBAD background operation cannot be interrupted by another operation. Hence, LPWAD, LP WAIT ANALOG TO DIGITAL, subroutine is also necessary. Specifically, LPWAD causes the calling program to wait until the element specified by the analog data array has been filled by the current burst or continuous background operation. Within the pressure transducer subroutine, an LPATV, LP ANALOG TO VOLTS operation is called. This routine converts an analog data value to a voltage value. The voltage can then be converted to a pressure with a few minor calculations and adjustments of the charge amplifier.

The final and most difficult subroutine of the program is the crank angle calculation. There are many factors to consider for this routine. Volume, time, speed, frequency, and actual engine dimensions are just a few. The frequency must be extremely high in order for the computer to be able to read the encoder shutters while operating the engine. A program that measures the volume of the cylinder has been completed, however; the implementation of the volume program with the encoder and crank angle routine is still being reviewed.

7.TESTING PROCEDURES

Prior to testing of the base case and test case, it was necessary to obtain some brief preliminary results from the engine operating on unleaded gasoline. This testing was performed as a basis for familiarizing the team with the ranges of the dynamometer and for comparison of torque and brake horsepower versus rpm. This testing was performed at a full throttle setting to compare with literature obtained from Honda. Graphical results can be seen in Appendix O.

Upon completion of the modified engine setup and programmed data acquisition system (for temperature and pressure readings), testing of the base case and test case was performed. Since this was the first time testing of any degree was to be performed on the Mars methane engine, procedures had to be developed. Many possibilities and options exist in order to comparatively test the base case and test case. Due to the limited testing time in the one semester period, the team felt that an adequate preliminary test constraint was to hold the inlet pressure constant in both cases. When operating the engine on methane and air, the aspiration plug is removed from the end of the mixing chamber to allow for air flow. This air flow is not regulated by a flowmeter. Therefore, measurement of the inlet pressure for the base case was limited to atmospheric conditions. When operating the engine on methane, carbon dioxide, and oxygen, the flowrates were adjusted to the same inlet pressure (approximately 1.0 atm.). With the inlet pressure held constant, the same rpm and torque values were set for each test. Temperature and pressures were then sampled by the data acquisition system and an exhaust sample was taken. These procedures will now be discussed on the following page.

PRELIMINARY BASE CASE TESTING:

1. Turn on water cooling supply for pressure transducer.
2. Set supply tanks to a back pressure of 60 kPa.
3. Close CH_4 flowmeter.
4. Connect 12V battery to dynamometer and turn on AC power supply.
5. Turn on engine switch.
6. Set dynamometer to Start Operational Mode, CW Field Mode, and HIGH Load Range.
7. Increase Field Load adjustment on dynamometer until shaft rotates.
8. Increase flowrate in methane flowmeter until combustion occurs.
9. Set Operational Mode to desired field load
10. Monitor flowrate, Field Load, and rpm until desired conditions are met.
11. Perform data acquisition for exhaust temperature and cylinder pressure.
12. Follow steps 1-7 in section 6 (exhaust gas analysis) for exhaust sample.
13. Reduce flowrate until combustion process ceases.
14. Turn off dynamometer, supply tank pressure.
15. Allow engine to cool (5-10 minutes minimum before disconnecting water supply to pressure transducer.

PRELIMINARY TEST CASE TESTING:

1. Repeat Steps 1 through 3 for all three gases and flowmeters. (above)
2. Repeat Steps 4-7. (above)
3. Supply excess amount of carbon dioxide to the mixing chamber along with required amounts of methane and oxygen.
4. Slowly decrease CO_2 (diluent) until combustion occurs.
5. Repeat Steps 9-15. (above)

These preliminary testing procedures were performed without the proper calculated ideal flowrates. Due to a lack of time, all stoichiometric and combustion calculations had not been completed prior to testing. The estimation of flowrates needed for combustion will result in the wasting of fuel and in turn, excess fuel in the products of combustion.

8. RESULTS

A set of preliminary results was obtained for both the base case and test case. These results include exhaust temperature, cylinder pressure as a function of time, and one exhaust sample for each case. Testing was performed while the engine operated at an inlet temperature of 1.0 atm., 2700 rpm, and a torque of 20 in-lbs. Results are shown in tabular and graphical form in Appendix P.

As indicated from the base case results, peak pressures ranged from approximately 180-200 psig. Results also show that the pressure inside the combustion chamber ha a minimum pressure of approximately -45 psig. This indicates that the combustion chamber is below atmospheric pressure, or operating similar to a vacuum. The numerical value of -45 psig is not ideal. The pressure inside the combustion chamber should never be less than -30 psig. The error in the data has resulted due to not calibrating the charge amplifier correctly. Future design teams must calibrate the charge amplifier in order to obtain more accurate and sufficient results.

As shown from the test case results, peak pressures ranged form approximately 90-130 psig. These values of pressure are slightly lower than the base case results. Results also show that the minimum pressure in the combustion chamber was approximately -30 psig. Again, an error has occurred due to the incorrect calibration of the charge amplifier.

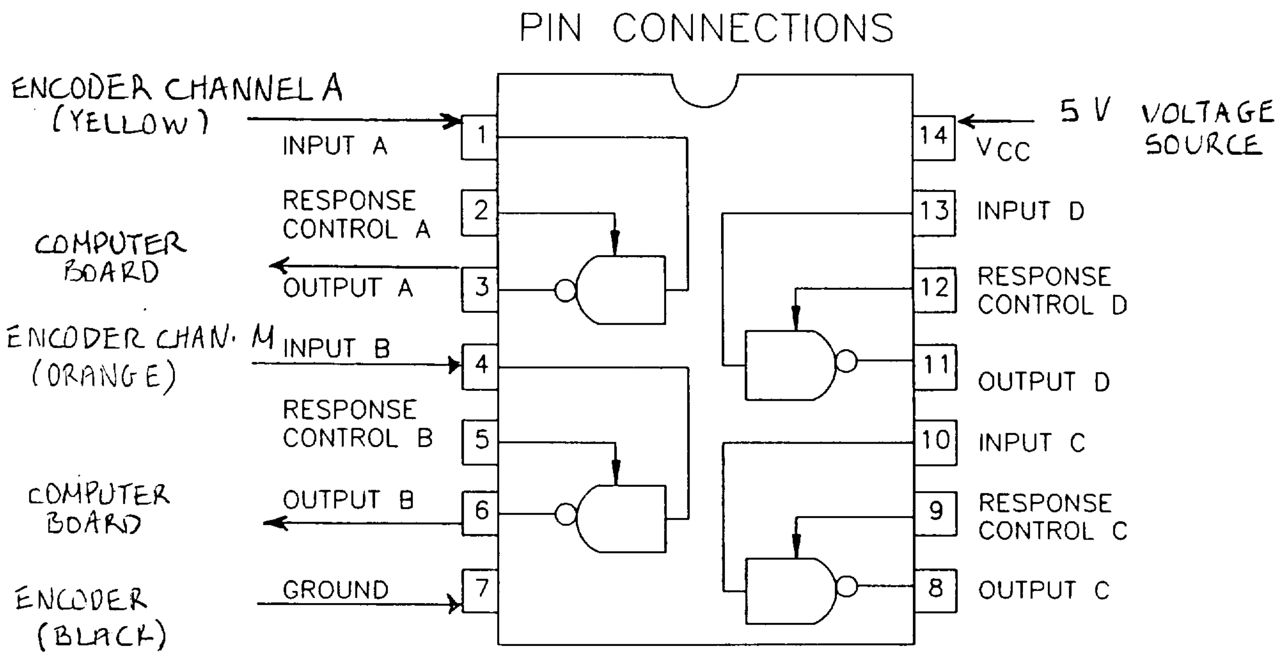
The exhaust temperatures for each of the different cases has been recorded in Appendix P. The exhaust temperature for the base case was about 570 (Celsius). The exhaust temperature for the test case was about 750 (Celsius).

From the exhaust gas analysis percent concentrations, it was found that the base case results show that the engine was operating with an excess of fuel. The exhaust gas analysis of the test case has not been returned to the design team from the Chemistry department.

9. FUTURE WORK PLAN

Future design teams working with this project will concentrate primarily on testing, optimization of fuel and consideration of the effects of the Martian atmosphere on engine operation. It was our goal to complete all required engine modifications, complete system setup, and begin preliminary testing. Each of these tasks were accomplished but some aspects of the overall project were not considered.

First, combustion analysis calculations should be completed in order to better understand flowrate settings and the interpretation of exhaust samples. A better understanding of the required flowrates will also minimize excess fuel. Secondly, calibration of the pressure transducer or adjustments in the charge amplifier settings may be necessary to obtain calibrated pressure readings. The tabular and graphical data for pressure as a function of time is indicating gage pressures below -30 psi (not possible). However, the readings are consistent and can be interpreted for comparative measures between the base case and test case. Appendix Q details the steps necessary for adjusting the charge amplifier for calibration. This process is simple but may not be as accurate as calibration with a dead weight tester. Third, and most important, is the programming and data acquisition of the incremental encoder. Due to an error by last semester's team in selecting a line driver encoder, proper corrections are required for operation. The encoder is designed to output a digital sine wave through the connecting cables as a function of current. The DT2811 hardware board accepts voltage inputs and is therefore incompatible. This problem may be remedied by placing a line receiver in series with the encoder connecting cables. A schematic of this receiver with the proper connections required is shown on the following page:



Once the data acquisition system is capable of reading the digital output from the encoder, it will then be necessary to coordinate the output with the positioning of "Top Dead Center" of the cylinder to transform the shaft angle into volume displacement. This information will then be coordinated with pressure readings to ultimately obtain graphical results of pressure versus volume. These results, along with accurate flowrate measurements, will establish the differences between the base case and test case and the optimization of fuel.

10. CONCLUSION

This semester has marked a turning point for the future of the Mars Methane Engine project. The installation of a new reliable Honda internal combustion engine will provide the accurate testing and results necessary for future design teams to build upon and draw conclusions. The engine has been completely modified and is capable of operating on the base case of methane and air as well as the test case of methane, carbon dioxide, and oxygen. Preliminary calculations for required air-to-fuel ratios of methane and air have been performed as a basis for future teams. Programming of the data acquisition system has been completed, with the exception of the incremental encoder, providing exhaust temperature and cylinder pressure. Some preliminary programming has been performed for the encoder and an additional program has been written to convert shaft angle rotation into volume displacement. Preliminary testing of the base case and test case have been performed for comparative results. Exhaust samples have been taken, for the first time ever, to be analyzed.

The successful completion of each of these aspects of the overall project will allow future teams to focus on testing of the test case. A fully operative data acquisition system will produce the pressure versus volume results crucial in engine cycle analysis.

All of the stated objectives in the initial proposal for the Mars Methane Engine have been fulfilled.

11. REFERENCES

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3. Campbell, Ashley, S., Thermodynamic Analysis of Combustion Engines, Robert E. Kreiger Publishing Company, Malabar Florida, 1986.

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6. GX120K1 Shop Manual, Honda Power Equipment, 1991 Honda Motor Co., Inc.

7. American Honda Motor Co., Inc., P.O. Box 100021 Duluth, Georgia 30136-9421. Phone: (404) 497-6400

12. APPENDICES

APPENDIX A

METHANE ENGINE

TASK DESCRIPTION	DATE	JAN	FEB	MAR	APR
REVIEW PREVIOUS WORK (all members)	AS: 1/1/93 EF: 2/5/93 AF: 2/1/93				
MODIFY EXHAUST SYSTEM (one member)	AS: 1/15/93 EF: 1/29/93 AF: 1/29/93				
MODIFY ENGINE SHAFT (one member)	AS: 1/15/93 EF: 1/29/93 AF: 1/22/93				
MODIFY CARBURETOR (one member)	AS: 1/15/93 EF: 1/29/93 AF: 2/1/93				
MOUNT PRESSURE TRANSDUCER ONTO ENGINE (one member)	ES: 1/29/93 EF: 2/12/93 AF: 2/14/93				
CONSTRUCT MOUNTING STAND (two members)	ES: 1/28/93 EF: 2/5/93 AF: 1/28/93				
ATTACH ENGINE TO DYNAMOMETER (two members)	ES: 2/12/93 EF: 2/26/93 AF: 1/29/93				
SETUP MEASURING DEVICES (three members)	ES: 2/12/93 EF: 2/26/93 AF: 3/1/93				

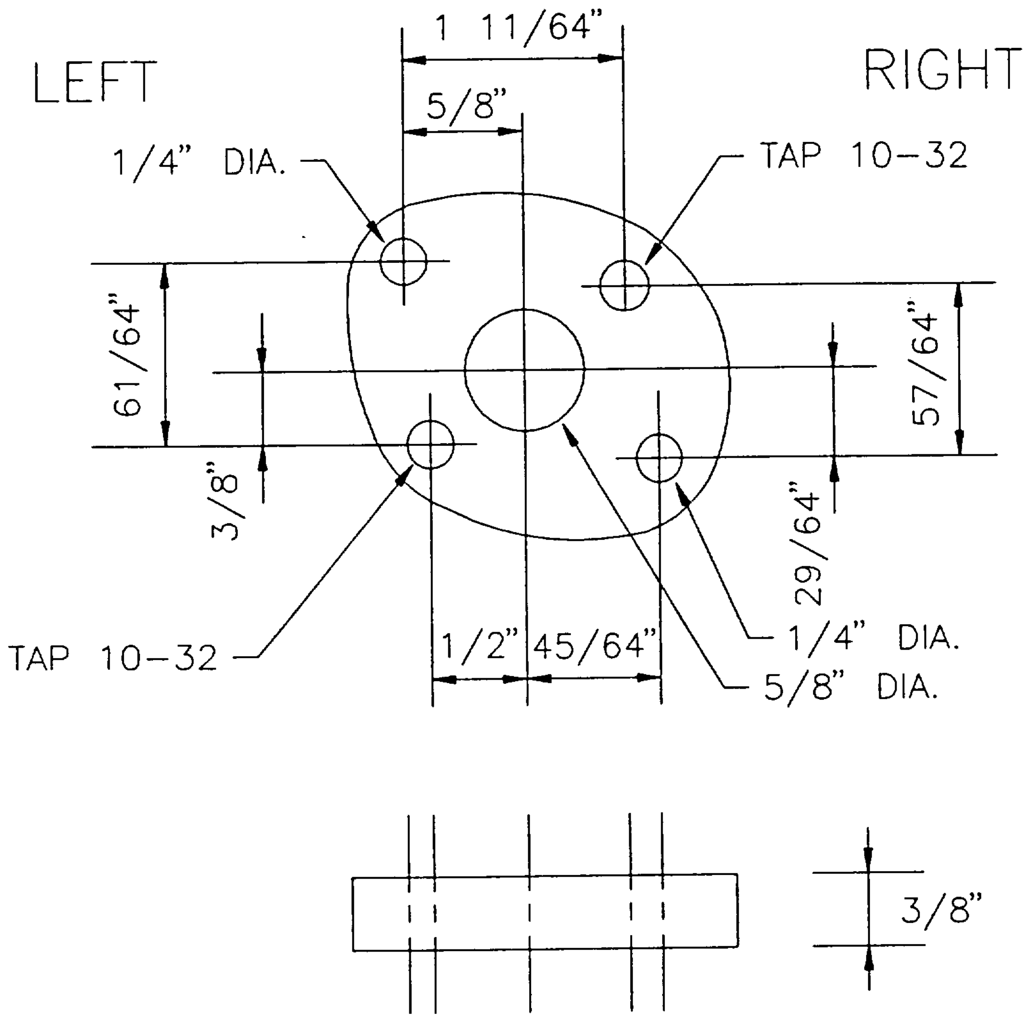
AS: Actual Start   ES: Estimated Start   EF: Estimated Finish   AF: Actual Finish

METHANE ENGINE

TASK DESCRIPTION	DATE	JAN	FEB	MAR	APR
STUDY DATA ACQUISITION SYSTEM (one member)	ES: 2/5/93 EF: 2/26/93 AF: 2/26/93				
STUDY EXHAUST GAS ANALYSIS (one member)	ES: 2/5/93 EF: 2/26/93 AF: 2/26/93				
INSTALL DATA ACQUISITION SYSTEM (two members)	ES: 2/19/93 EF: 3/1/93 AF: 3/15/93				
FLOW METER CALIBRATION (two members)	ES: 2/19/93 EF: 3/1/93 AF: 2/26/93				
ACQUIRE EXHAUST GAS CYLINDERS (one members)	ES: 2/19/93 EF: 3/5/93 AF: 2/12/93				
RUN ENGINE WITH BASE CASE AND COLLECT DATA (all members)	ES: 3/5/93 EF: 3/26/93 AF: 4/12/93				
RUN ENGINE WITH TEST CASE AND COLLECT DATA (all members)	ES: 3/26/93 EF: 4/15/93 AF: 4/15/93				
FINAL REPORT (all members)	ES: 4/2/93 EF: 4/21/93 AF: 4/20/93				

AS: Actual Start ES: Estimated Start EF: Estimated Finish AF: Actual Finish

APPENDIX B



CARBURETOR ADAPTOR

SCALE: FULL

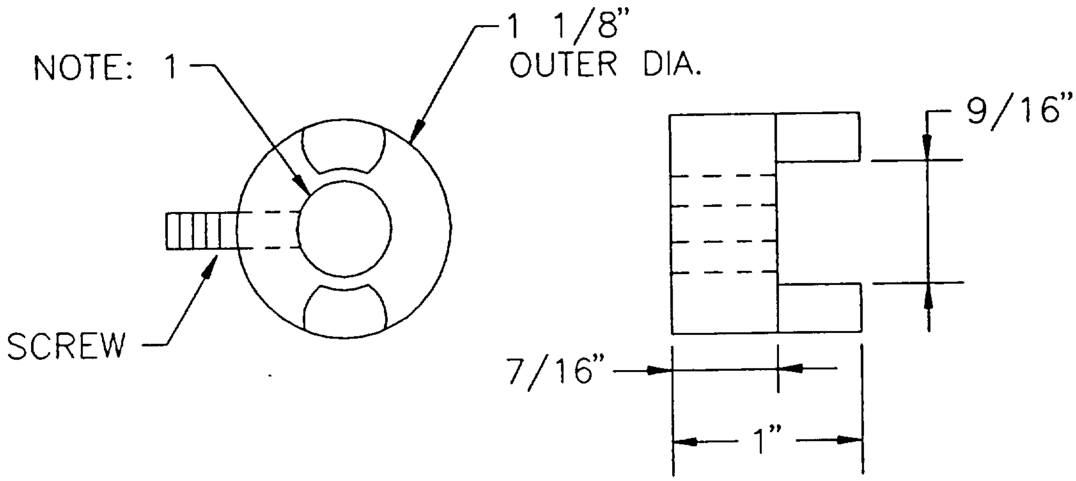
MARS METHANE ENGINE

SENIOR DESIGN PROJECT MEM434

LAWRENCE, HOOVER, LAUER, TAYLOR, & PAPARISTODEMOU

SHT. 2

APPENDIX C

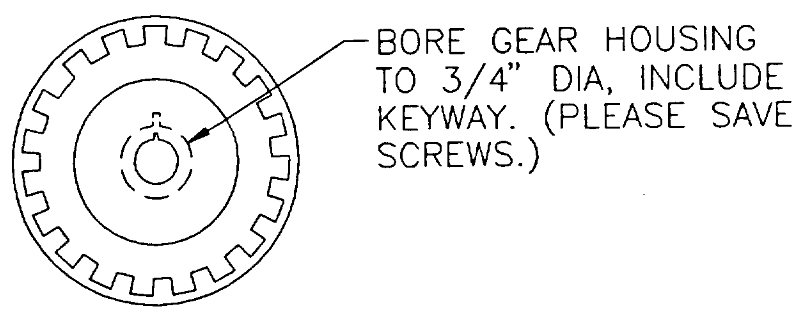


LOVEJOY L-050 5000

SCALE: FULL

NOTE:

1. BORE THIS HOLE AND THREAD TO MATCH THREADED END OF SHAFT ON HONDA ENGINE. PLEASE SAVE SCREW.



GEAR HOUSING

NOT TO SCALE

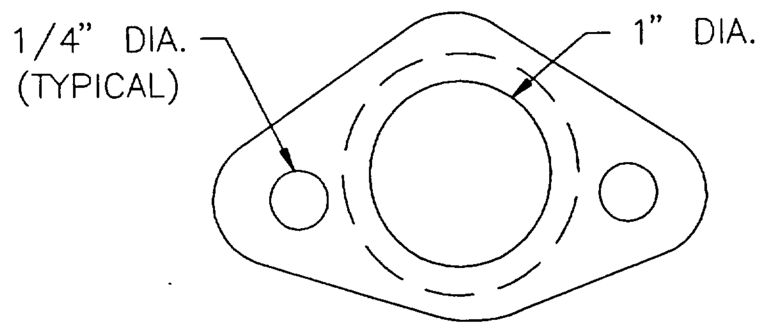
MARS METHANE ENGINE

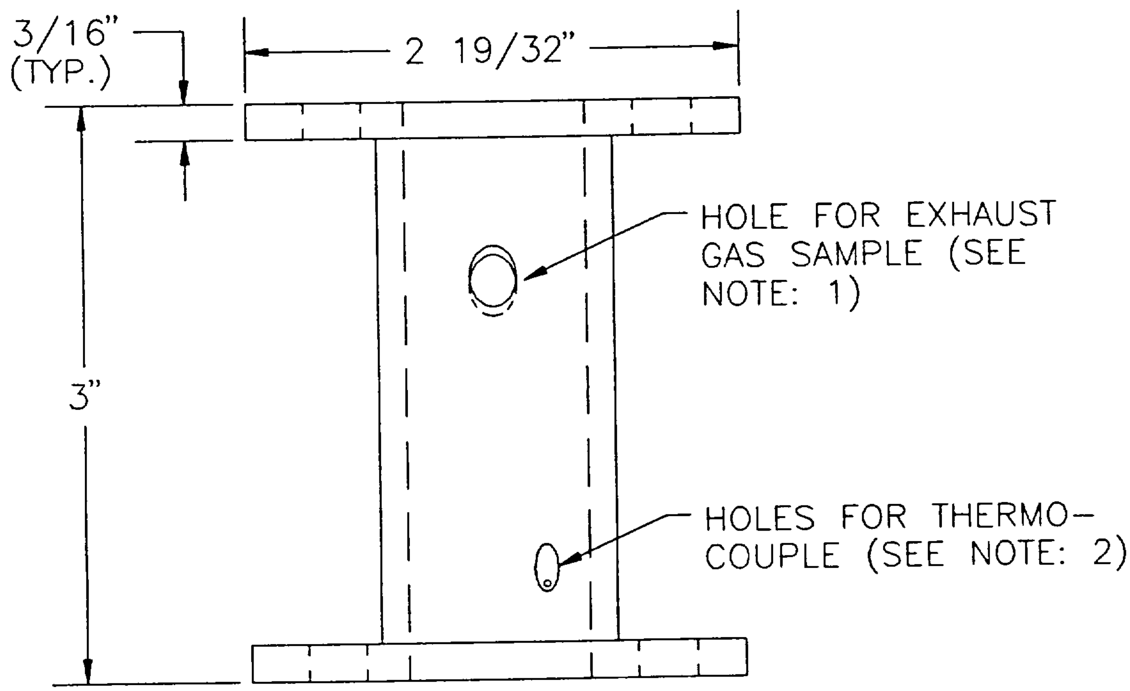
SENIOR DESIGN PROJECT MEM434

LAWRENCE, HOOVER, LAUER, TAYLOR, & PAPARISTODEMOU

SHT. 5

APPENDIX D





MUFFLER EXTENSION

SCALE: FULL

NOTES:

1. DRILL 1/4" DIA. HOLE AT A 15° ANGLE.
2. DRILL 1/8" OUTER DIA. HOLE AND 1/16" DIA. INNER HOLE, BOTH AT A 60° ANGLE.
3. MATERIAL SHALL BE ALUMINUM.

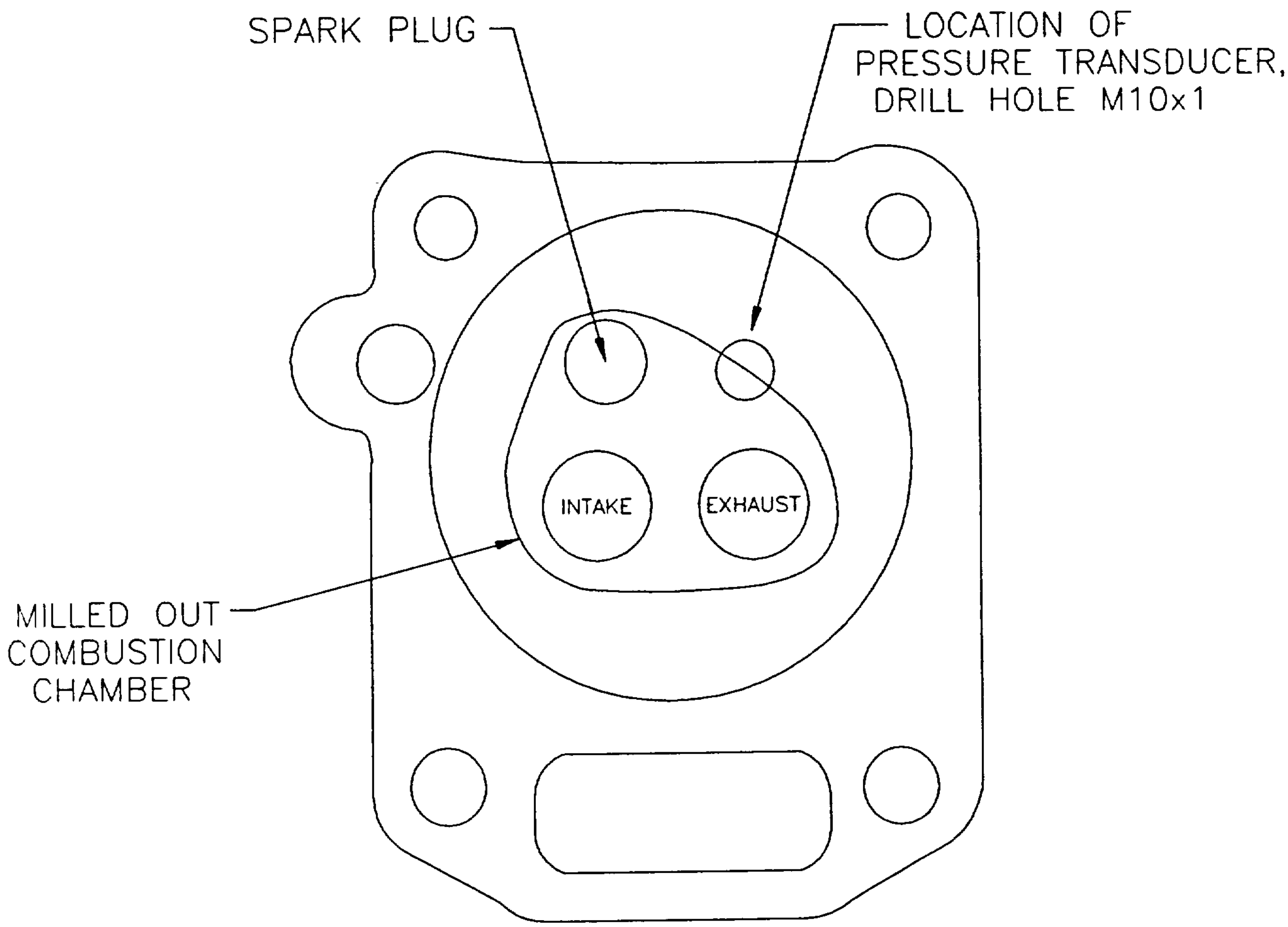
MARS METHANE ENGINE

SENIOR DESIGN PROJECT MEM434

LAWRENCE, HOOVER, LAUER, TAYLOR, & PAPARISTODEMOU

SHT. 3

APPENDIX E



LOCATION OF
PRESSURE TRANSDUCER

SCALE: FULL

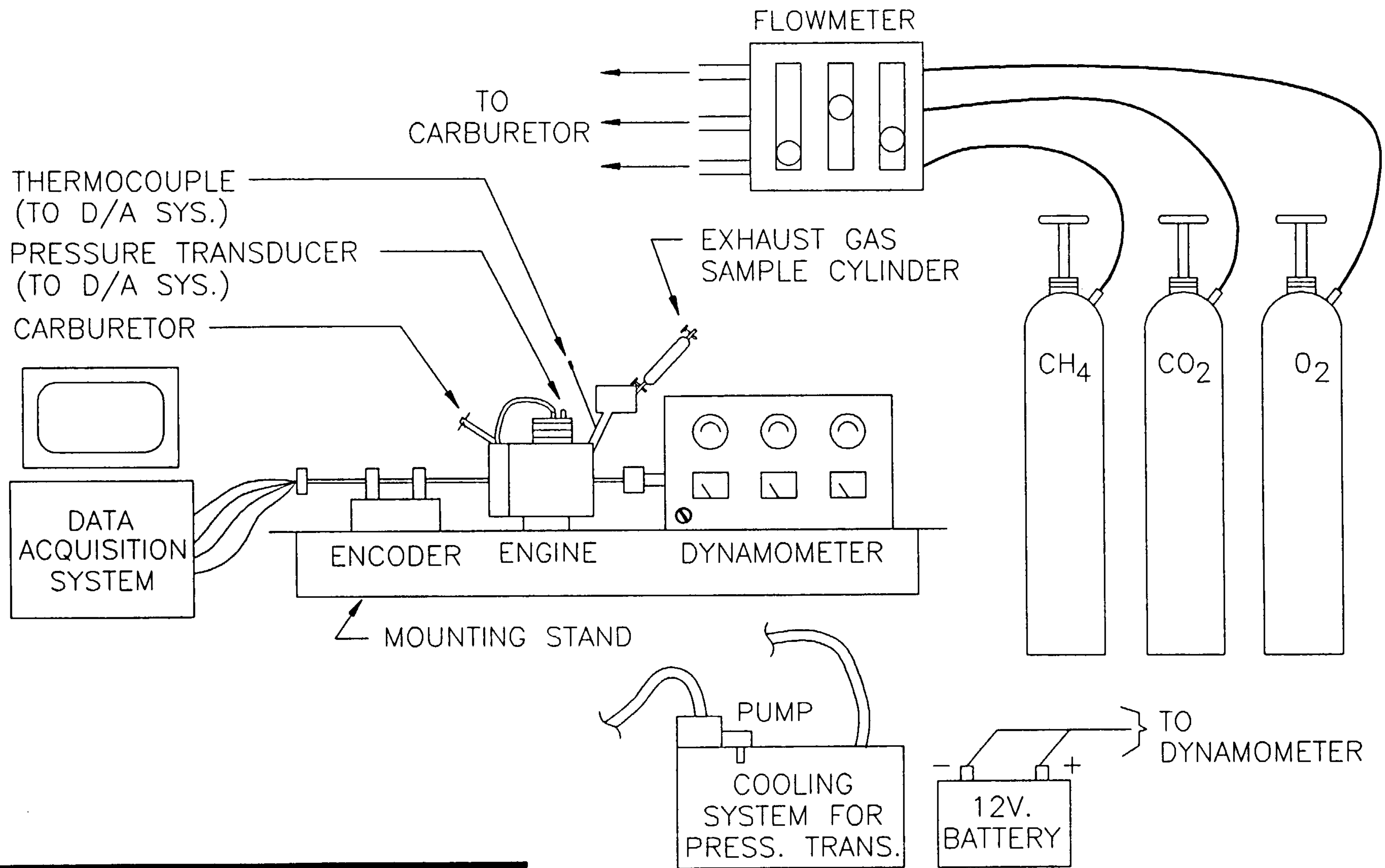
MARS METHANE ENGINE

SENIOR DESIGN PROJECT MEM434

LAWRENCE, HOOVER, LAUER,
TAYLOR, & PAPARISTODEMOU

SHT. 4

APPENDIX F



PROJECT SET-UP

MARS METHANE ENGINE

SENIOR DESIGN PROJECT MEM434

LAWRENCE, HOOVER, LAUER, TAYLOR, & PAPARISTODEMOU

SHT. 1

APPENDIX G

C	SEE ECO 1315	2-22-84	[illegible]
A-3 D	ECO 1728	2-12-85	[illegible]

CHARGE AMPLIFIER FOR PRESSURE TRANSDUCER:

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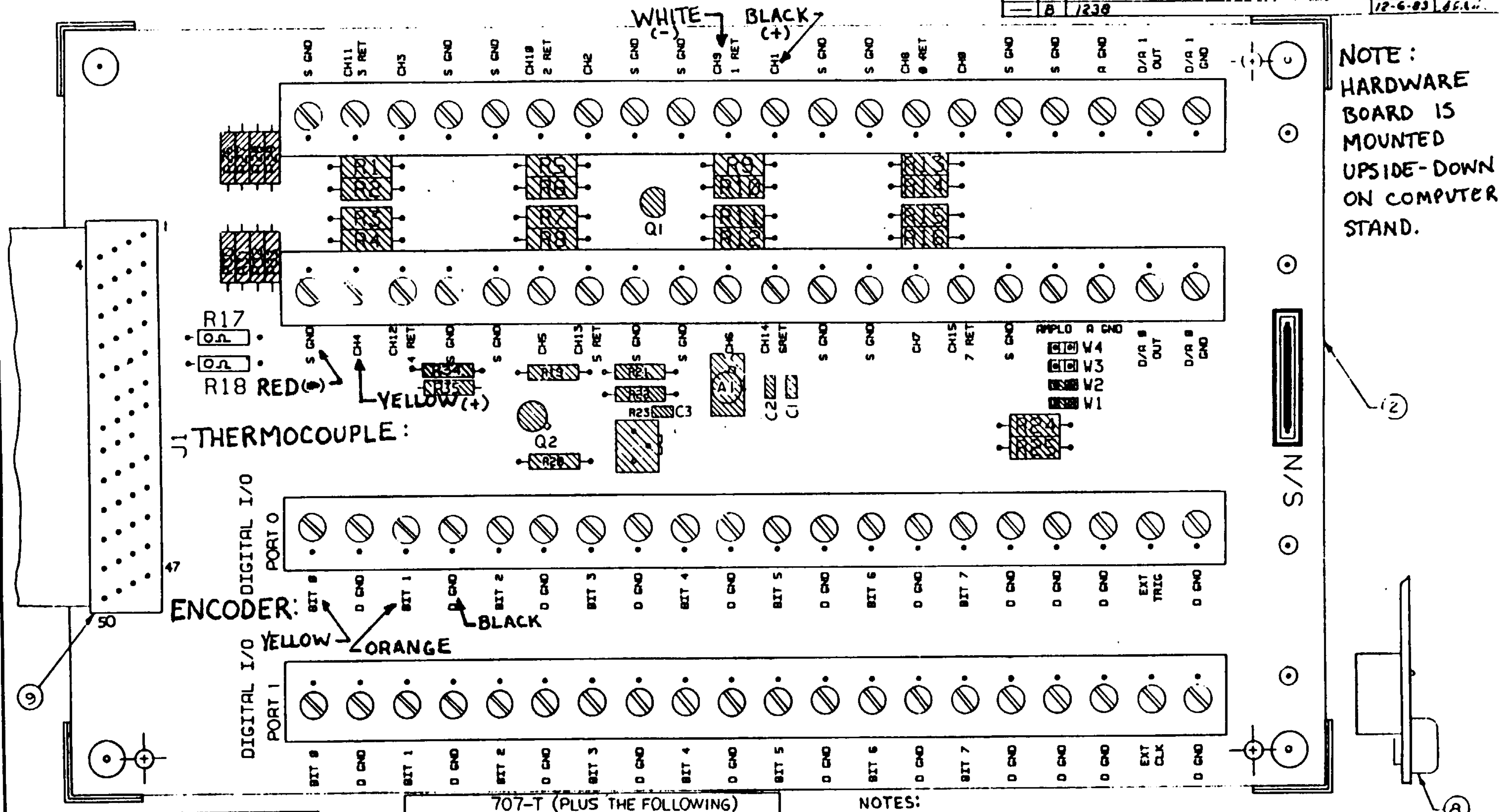
REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED
—	Ø	ENGINEERING PROTOTYPE	9-1-83	[illegible]
—	1	REVISED	2-11-83	[illegible]
—	A	RELEASED FOR PRODUCTION	10-03-83	[illegible]
—	B	1238	12-6-83	[illegible]



707	
REF DES	DESCRIPTION
	BARRIER STRIP
J1	CABLE ASSY
R17, R18	0Ω
W3, W4	JUMPER & PINS

707-M	
	BARRIER STRIP
J1	CABLE ASSY
R17, R18	0Ω
W3, W4	JUMPER & PINS
R1, R4, R5, R8, R9, R12, R13, R16	250 Ω .05%
R2, R3, R6, R7, R10, R11, R14, R15	10K

707-T (PLUS THE FOLLOWING)	
REF DES	DESCRIPTION
A1	OP21GP
C1, C2, C3	.1UF
R2, R3, R6, R7, R10, R11, R14, R15, R21	10K
R19	169K
R20	10.7K
R22	TRIM
R23	500 Ω
R24	4K .05%
R25	1K .02%
R26 THRU R33	100MEG
R35	12K
Q1	2N5088
Q2	LH0070-0H
W1, W2	JUMPER & PINS

R34	2.2K

NOTES:

1. R22 TO BE MATCHED TO Q1
2. FOR LIST OF MATERIALS SEE A SIZE DWG 00818

QTY	ITEM	PART NO.	DESCRIPTION	MFR. DWG.

LIST OF MATERIALS

DATA TRANSLATION
MARLBORO, MASSACHUSETTS 01752

TITLE: COMPONENT BOARD ASSEMBLY DT707 (TABULATED)

MATERIAL: N/A
FINISH: N/A
SIZE: C
DRAWING NO. 00817
REV. D
NEXT ASSY 00818
USED ON DT707
SCALE NONE
SHEET 1 OF 1

APPENDIX H

COMBUSTION EQUATION *1 MOLE OF FUEL

$$CH_4 + YO_2 + 3.76YN_2 \rightarrow n_{CO_2}CO_2 + n_{H_2O}H_2O + n_{O_2}O_2 + n_{CO}CO + n_{N_2}N_2$$

$n_{CO_2} \rightarrow$ # OF MOLES OF CO_2
$n_{H_2O} \rightarrow$ # OF MOLES OF H_2O
$n_{O_2} \rightarrow$ # OF MOLES OF O_2
$n_{CO} \rightarrow$ # OF MOLES OF CO
$n_{N_2} \rightarrow$ # OF MOLES OF N_2

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

CASE I CHEMICALLY CORRECT ($Y = Y_{cc}$)

$n_{O_2} = 0$, $n_{CO} = 0$; $n_{CO_2} = MC$
$n_{H_2O} = MH/2$; $n_{N_2} = 3.76\,Y_{cc}$

O_2 Balance: $Y_{cc} + \frac{MO}{2} = n_{CO_2} + n_{H_2O}/2 = MC + \frac{MH}{4}$

$$Y_{cc} = MC + MH/4 - MO/2$$

$\boxed{EX}$ $CH_4 + Y_{cc}O_2 + Y_{cc}(3.76)N_2 \rightarrow CO_2 + 2H_2O + Y_{cc}(3.76)N_2$

$MC = 1$, $MH = 4$, $n_{H_2O} = \frac{MH}{2} = 2$, $n_{N_2} = (3.76)Y_{cc}$, $MO = 0$

$Y_{cc} = 1 + 4/4 - 0/2$ ∴ $Y_{cc} = 2$

$$\boxed{CH_4 + 2O_2 + 2(3.76)N_2 \rightarrow CO_2 + 2H_2O + 2(3.76)N_2}$$

CASE II MINIMUM AMOUNT OF AIR PRESENT ($Y = Y_{min}$)

$n_{O_2} = 0$; $n_{CO_2} = 0$; $n_{H_2O} = MH/2$, $n_{CO} = MC$, $n_{N_2} = 3.76\,Y_{min}$

O_2 Balance: $Y_{min} + \frac{MO}{2} = \frac{n_{CO}}{2} + \frac{n_{H_2O}}{2} = \frac{MC}{2} + \frac{MH}{4}$

$$Y_{MIN} = \frac{MC}{2} + \frac{MH}{4} - \frac{MO}{2}$$

$$Y_{MIN} = Y_{cc} - \frac{MC}{2}$$

$\boxed{EX}$ $CH_4 + Y_{MIN}O_2 + Y_{MIN}(3.76)N_2 \rightarrow CO + 2H_2O + Y_{MIN}(3.76)N_2$

$MC = 1$, $MH = 4$, $n_{H_2O} = \frac{MH}{2} = 2$, $n_{CO} = 1$, $n_{N_2} = 3.76\,Y_{min}$, $MO = 0$

$$Y_{MIN} = \frac{MC}{2} + \frac{MH}{4} - \frac{MO}{2} = \frac{1}{2} + \frac{4}{4} - 0$$

$Y_{MIN} = 1.5$

$$\boxed{CH_4 + 1.5O_2 + 1.5(3.76)N_2 \rightarrow CO + 2H_2O + 1.5(3.76)N_2}$$

CASE III EXCESS AIR $Y > Y_{cc}$

PRODUCTS: $n_{H_2O} H_2O + n_{CO_2} CO_2 + n_{O_2} O_2 + n_{N_2} N_2$

$$n_{CO} = 0 \ , \quad n_{H_2O} = \frac{MH}{2} \ , \quad n_{CO_2} = MC \ , \quad n_{N_2} = 3.76Y \ , \quad MO = 0$$

O_2 Balance:

$$Y + \frac{MO}{2} = \frac{n_{H_2O}}{2} + n_{CO_2} + n_{O_2}$$

$$n_{O_2} = Y + \frac{MO}{2} - \frac{MH}{4} - MC$$

$$\underline{\underline{n_{O_2} = Y - Y_{cc}}}$$

CASE IV EXCESS FUEL $Y_{min} < Y < Y_{cc}$

PRODUCTS: $n_{H_2O} H_2O + n_{CO_2} CO_2 + n_{CO} CO + n_{N_2} N_2$

$$n_{O_2} = 0 \ ; \quad n_{N_2} = 3.76Y \ ; \quad n_{H_2O} = \frac{MH}{2} \qquad MO = 0$$

$$n_{CO} = ? \qquad n_{CO_2} = ?$$

$$MC = n_{CO} + n_{CO_2}$$

$$n_{CO_2} = MC - n_{CO}$$

O_2 Balance:

$$Y + \frac{MO}{2} = \frac{n_{CO}}{2} + n_{CO_2} + \frac{n_{H_2O}}{2}$$

$$Y + \frac{MO}{2} = \frac{n_{CO}}{2} + MC - n_{CO} + \frac{MH}{4}$$

Solve for n_{CO} to get:

$$n_{CO} = 2(Y_{cc} - Y)$$

$$\underline{\underline{n_{CO_2} = 2(Y - Y_{min})}}$$

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

[1]

<u>ASSUME:</u> 100% THEORETICAL AIR

$$CH_4 + Y_{cc}\,O_2 + Y_{cc}(3.76)N_2 \rightarrow n_{CO_2}\,CO_2 + n_{H_2O}\,H_2O + n_{N_2}\,N_2$$

<u>COMPLETE COMBUSTION:</u>

$MC = 1$, $MH = 4$, $MO = 0$ IN FUEL

$$Y_{cc} = MC + \frac{MH}{4} - \frac{MO}{2} = 1 + \frac{4}{4} \rightarrow \underline{Y_{cc} = 2}$$

$$n_{N_2} = 3.76 * Y_{cc} = 7.52$$
$$n_{CO_2} = MC = 1$$
$$n_{H_2O} = \frac{MH}{2} = 2$$

$$\therefore\ CH_4 + 2O_2 + 2(3.76)N_2 \rightarrow CO_2 + 2H_2O + 7.52\,N_2$$

$$\left.\frac{AIR}{FUEL}\right)_{MOLE} = \frac{KMOL\ AIR}{KMOL\ FUEL} = \frac{4.76\,Y_{cc}}{1} = 9.52\ \frac{Kmol\ Air}{Kmol\ Fuel}$$

$$\left.\frac{AIR}{FUEL}\right)_{MASS} = \left.\frac{A}{F}\right)_{MOLE}\left(\frac{MW\,AIR}{MW\,FUEL}\right) = \left(9.52\ \frac{Kmol\ Air}{Kmol\ Fuel}\right)\left(\frac{28.97\ \frac{Kg\ Air}{Kmol\ Air}}{16.043\ \frac{Kg\ Fuel}{Kmol\ Fuel}}\right)$$

$$\left.\frac{Air}{Fuel}\right)_{MASS} = \underline{17.191\ \frac{Kg\ Air}{Kg\ Fuel}}$$

<u>FIRST LAW FOR REACTING SYSTEM:</u> SSSF, 1 KMOL OF FUEL BASIS

* STND. CONDITIONS $P = .1MPa$, $T = 298K$

$$H_R = H_P \quad \therefore \quad \sum_R n_i \bar{h}_i = \sum_P n_e \bar{h}_e$$

$$1\left(\bar{h}_f^\circ + \Delta\bar{h}_{*\to T_R,P_R}\right)_{CH_4} + 2\left(\bar{h}_f^\circ + \Delta\bar{h}_{*\to T_R,P_R}\right)_{O_2} + 7.52\left(\bar{h}_f^\circ + \Delta\bar{h}_{*\to T_R,T_R}\right)_{N_2} =$$

$$1\left(\bar{h}_f^\circ + \Delta\bar{h}_{*\to T_P,P_P}\right)_{CO_2} + 2\left(\bar{h}_f^\circ + \Delta\bar{h}_{*\to T_P,P_P}\right)_{H_2O} + 7.52\left(\bar{h}_f^\circ + \Delta\bar{h}_{*\to T_P,P_P}\right)_{N_2}$$

<u>ASSUME:</u> $P_R = .1MPa$, $T_R = 25°C = 298K$

$$\therefore\ \Delta\bar{h}_{*\to T_R,P_R}\Big)_{CH_4} = 0$$
$$\Delta\bar{h}_{*\to T_R,P_R}\Big)_{O_2} = 0$$
$$\Delta\bar{h}_{*\to T_R,P_R}\Big)_{N_2} = 0$$

<u>CHEMICAL REF. STATE</u>

$$\bar{h}_f^\circ\Big)_{O_2} = 0$$
$$\bar{h}_f^\circ\Big)_{N_2} = 0$$

<u>TABLE A-13</u> REF. (1)

$$\bar{h}_f^\circ\Big)_{CH_4} = -74\,873\ \frac{KJ}{Kmol}$$
$$\bar{h}_f^\circ\Big)_{CO_2} = -393\,522\ \frac{KJ}{Kmol}$$
$$\bar{h}_f^\circ\Big)_{H_2O} = -241\,827\ \frac{KJ}{Kmol}$$

$$\Delta\bar{h}_{*\to T_P,P_P}\Big)_{CO_2,\ H_2O,\ N_2}$$

ASSUME: IDEAL GASES $\therefore$ PRESSURE IS IRRELAVENT

DO NOT ASSUME: CONSTANT C_{P_0}

$$\Delta\bar{h} = \bar{h}(T_P) - h(298)$$

AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

FIRST LAW FOR REACTING SYSTEM BECOMES:

$$1\left(-74873\ \frac{KJ}{Kmol}\right) = 1\left(-393522\ \frac{KJ}{Kmol} + \Delta\bar{h}_{\to T_P,P_P}\right)_{CO_2} + 2\left(-241827 + \Delta\bar{h}_{\to T_P,P_P}\right)_{H_2O}$$

$$+\,7.52\left(\Delta\bar{h}_{\to T_P,P_P}\right)_{N_2}$$

$$0 = -802303\ \frac{KJ}{Kmol} + \left(\Delta\bar{h}_{\to T_P,P_P}\right)_{CO_2} + 2\left(\Delta\bar{h}_{\to T_P,P_P}\right)_{H_2O} + 7.52\left(\Delta\bar{h}_{\to T_P,P_P}\right)_{N_2}$$

TO SOLVE FOR $F(\hat{T}_P) = 0$, ASSUME VALUES FOR T_P USING <u>TABLE A-11</u> REF (1).

① $T_P = 2300\text{ K}$

$\Delta\bar{h})_{CO_2} = 109671\ KJ/Kmol$

$\Delta\bar{h})_{H_2O} = 88295\ KJ/Kmol$

$\Delta\bar{h})_{N_2} = 67007\ KJ/Kmol$

$F(\hat{T}_P)_{2300K} = -12149.36\ KJ/Kmol$

② $T_P = 2400\text{ K}$

$\Delta\bar{h})_{CO_2} = 115788\ KJ/Kmol$

$\Delta\bar{h})_{H_2O} = 93604\ KJ/Kmol$

$\Delta\bar{h})_{N_2} = 70651\ KJ/Kmol$

$F(\hat{T}_P) = 31988.52\ KJ/Kmol$

<u>BY INTERPOLATION</u>:

$$\frac{T_P - 2300\text{ K}}{2400\text{K} - 2300\text{ K}} = \frac{0 - (-12149.36\ KJ/Kmol)}{(31988.52\ KJ/Kmol) - (-12149.36\ KJ/Kmol)}$$

$$T_P - 2300\text{K} = 27.526$$

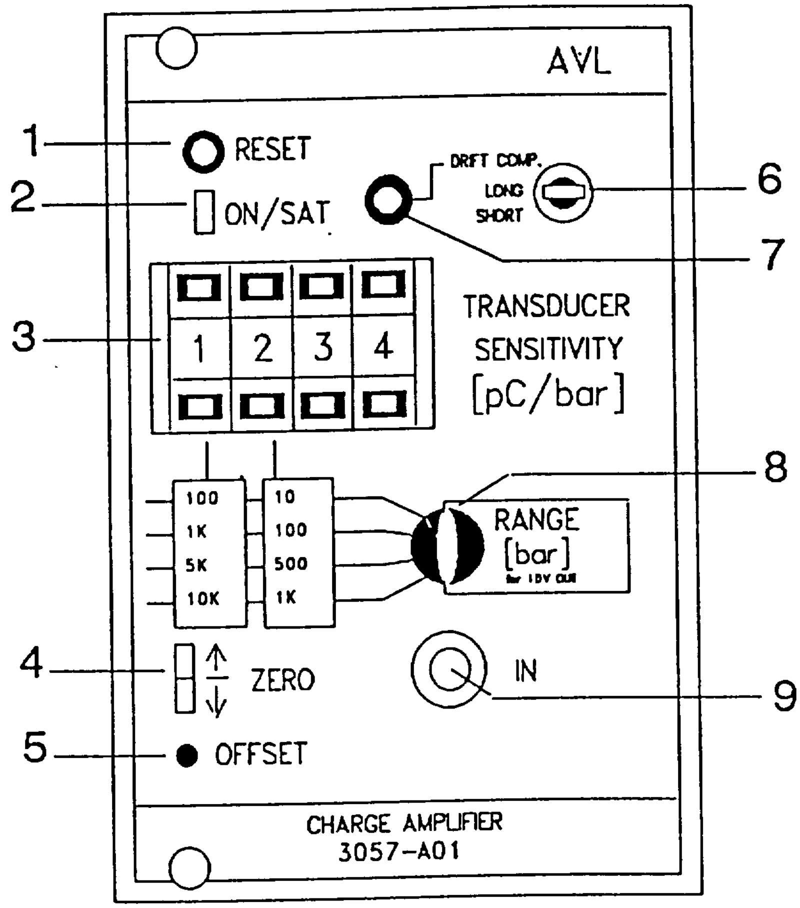
$$\underline{\underline{T_P = 2327.5\text{ K}}}$$

ADIABATIC FLAME TEMPERATURE: FOR CHEMICALLY CORRECT, IDEAL, COMPLETE COMBUSTION OF METHANE IN AIR.

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

APPENDIX J

AVL 3057-A01 CHARGE AMPLIFIER



1) RESET:
Push button for discharging feedback capacitor.

2) ON/SAT (2 functions):
a) Power supply check light. Illuminated during operation
b) Saturation indicator: flashes when amplifier is driven into saturation.

3) TRANSDUCER SENSITIVITY:
Four-digit digital potentiometer for input of transducer sensitivity in pC/bar.

4) ZERO:
Indicates any deviation of the zero point from the quiescent potential in positive or negative direction.

5) OFFSET
Setting zero when RESET button is pressed. Check: neither ZERO LED is illuminated.

6) LONG/SHORT/DRIFT COMP.:
Operational mode selector switch
LONG :quasi-static measurement
SHORT :dynamic measurement

7) DRIFT COMP. LED
Not applicable.

8) RANGE:
Measuring range selector: 4-level decadic setting of measuring range; depending on decimal point of the measurement transducer sensitivity, one of the two columns will apply showing relevant input pressure for 10V output voltage.

9) IN
High insulation signal input connector socket for connecting pressure transducer with special high insulation, low noise cable.

APPENDIX K

Basics-Incremental Encoders

Closed Loop Systems

In closed loop systems, incremental encoders generate the vital data required to establish angular position, provide velocity feedback information and determine direction of rotation. Basically, a rotary encoder converts angular motion into a digital output format that's easily interfaced with computers and programmable controllers.

Basic Operation of an Incremental Encoder

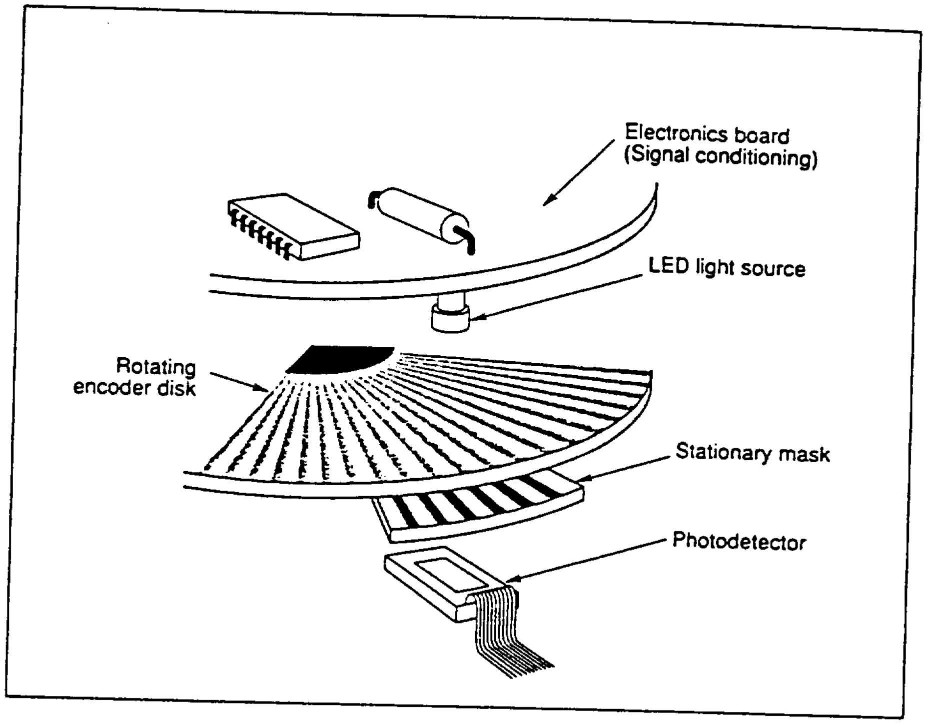
A rotary incremental optical encoder has five main components:

1. **LED light source.**
2. **Rotating encoder disk.**
3. **Stationary mask.**
4. **Photodetector.**
5. **Electronics to amplify and square the output signals from the photodetector.**

As the encoder disk rotates in front of the mask, it shutters the light from the LED light source. The light energy that passes through the mask is received by the photodetector which produces pulses in the form of a quasi-sine wave output. The encoder electronics convert the sine wave output into a square wave form, ready for transmission to a counter.

All Lucas Ledex standard encoders also include a single marker which provides one pulse every 360° of mechanical rotation for reference to determine a home base position.

Incremental Rotary Encoder

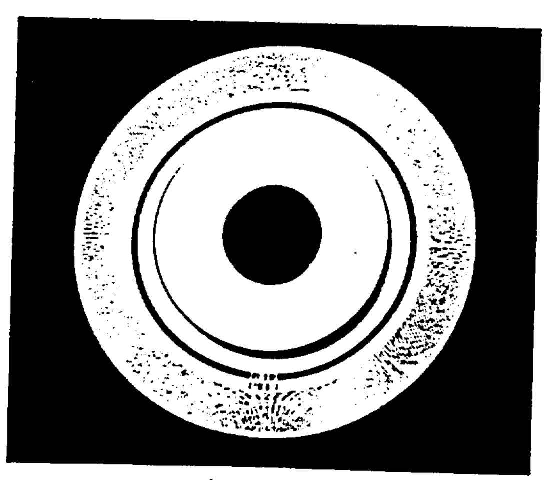


Incremental Encoder Benefits

- *Digital output.*
- *Angular or linear position sensing.*
- *Angular or linear direction of movement.*
- *Marker pulse for home base reference or error detection.*
- *Outputs compatible with control interfaces.*
- *Broad product range to meet application cost targets and performance requirements.*

Encoder Disk

The encoder disk is the critical component in determining the overall performance of the encoder. The position and spacing of the lines on the disk requires a high degree of precision. The number of lines is equal to the number of pulses per revolution. While physical limitations determine the number of lines that can be established on any given disk, multiplication techniques make it possible to increase the resolution of quadrature type encoders by a factor of four (see page 7).



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Tachometer Encoders

A single output incremental encoder, often referred to as a tachometer, is normally used in systems requiring accurate, but simple position or velocity information. Velocity data is generated by looking at the time interval between pulses or the number of pulses within a given time period.

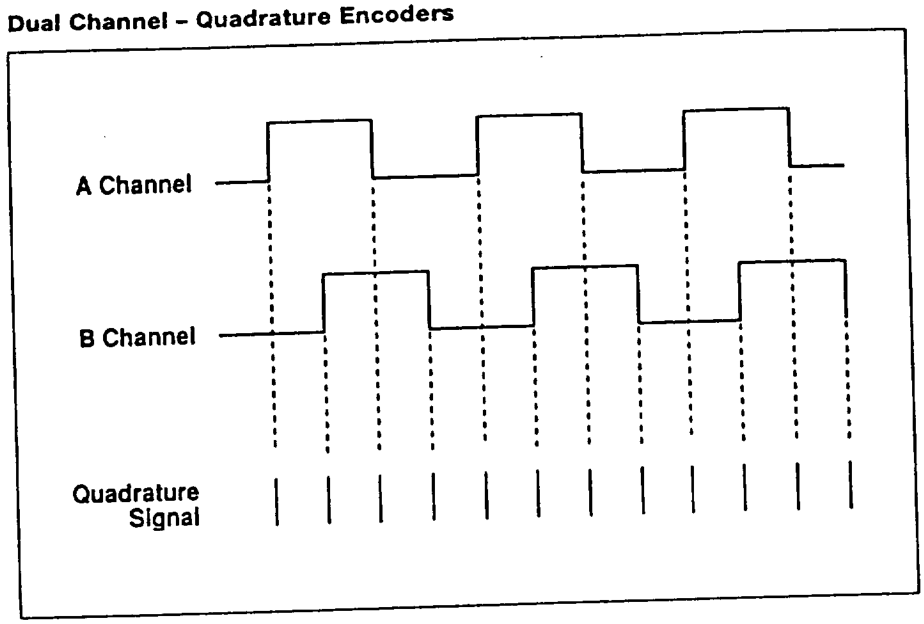
Quadrature Encoders

Quadrature encoders have dual channels, A and B, which are phased 90° electrically apart. An important benefit of having two output signals is that the direction of rotation can be determined by monitoring the phase relationship between these two channels.

Resolution Multiplication

Another important benefit of quadrature encoders is the capability of providing very high resolutions by multiplying the number of output pulses. In a dual channel encoder, a four times multiplication of the output count or resolution can be achieved by externally counting the rising and falling edges of each channel (A and B). A 5,000 pulses per revolution quadrature encoder, for example, can generate 20,000 pulses per revolution by employing this technique.

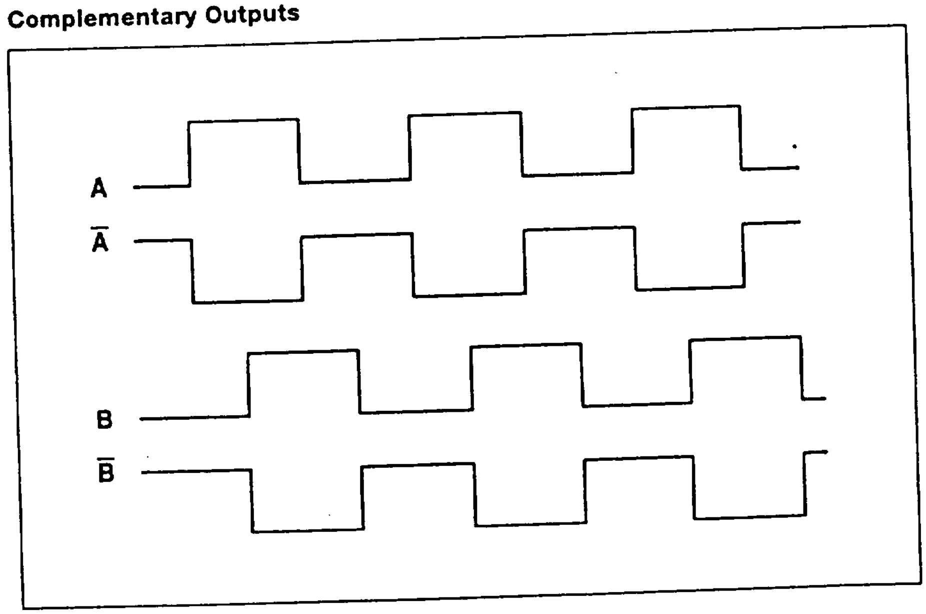
Dual Channel – Quadrature Encoders



Complementary Outputs

In addition to the need to count pulses accurately, correct position feedback depends on eliminating any false signals resulting from electrical noise. Incremental encoders are susceptible to noise, especially when the encoder cable is in the proximity of large electrical motors or switching gear. Noise problems can be eliminated or greatly reduced by using an encoder that provides complementary outputs. As shown here, a correct signal will generate two simultaneous outputs. As channel A goes high, channel $\bar{A}$ goes low. If this doesn't occur, the signal is assumed to be the result of electrical noise and is ignored.

Complementary Outputs



Tel: (513) 898-3621
Fax: (513) 898-8624
Lucas Ledex

K3 Series

Incremental Encoder
Modular
Resolution to 2,540 ppr

The K3 modular optical encoder consists of two major components: an optically encoded disk on a precision bored hub which mounts on the motor shaft, and an LED light source/photocell detector assembly which mounts on the motor endbell. The encoder is factory adjusted to minimize the installation time of the user.

One or two output channels and an optional index pulse are available in a 2.1 inch diameter case. Resolutions of up to 2,540 ppr are provided. Depending on the application, three types of disks are available: metal deposition on glass, photoemulsion on plastic and etched metal.

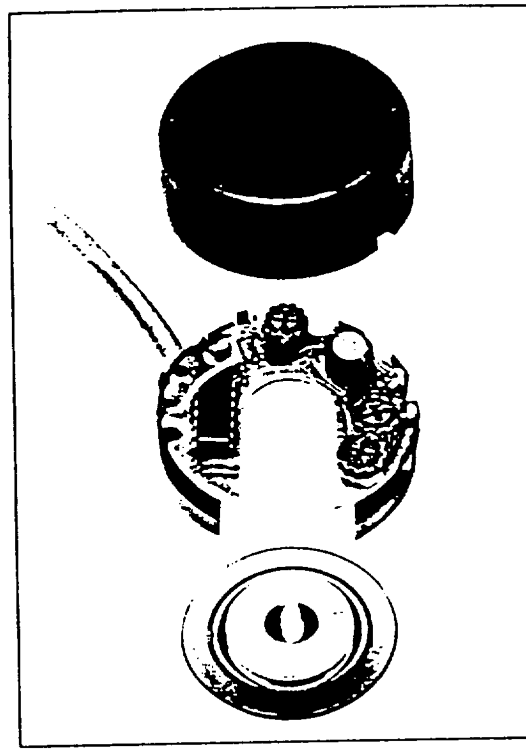
A single LED light source and a monolithic sensor array render the K3 encoder less sensitive to the effects of power supply variation and component aging. The use of a collimating lens and the radial sensor array reduce the sensitivity of the encoder to motor shaft runout and wobble.

Features

- ☐ Resolution to 2,540 ppr
- ☐ Single-ended, single-ended with complements or line driver output
- ☐ Easy to install
- ☐ Single LED light source
- ☐ Monolithic sensor array
- ☐ +5 or +12VDC power supply

Applications

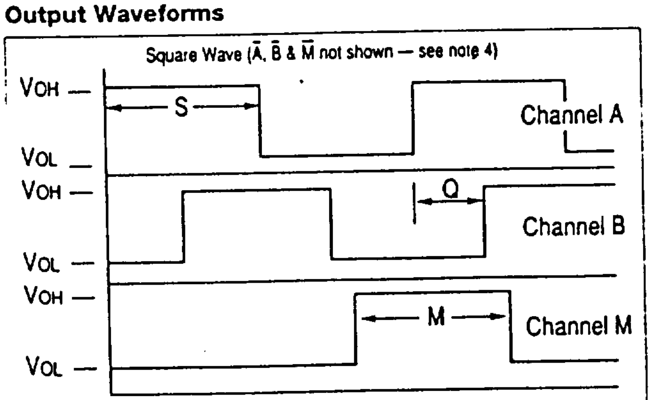
- ☐ Computer printers
- ☐ Microfiche readers
- ☐ Phototypesetters
- ☐ Tape transports
- ☐ Digital plotters
- ☐ Semiconductor processing
- ☐ X-Y tables
- ☐ Medical diagnostic equipment



Electrical Specifications

Output Configuration	Single-ended	Buffered 7404 and Complementary Output	Line Driver
Supply Voltage, Vs	5VDC ±5% or 12VDC ±5%	5VDC ±5%	5VDC ±5%
Max. Supply Current	80 ma	120 ma	150 ma
VOH (logic "1")	Vs	2.4V min.	These characteristics vary with cable length and receiver circuitry
VOL (logic "0")	0.5V max.	0.4V max.	
Signal Risetime (10% to 90%)	1.0 µ sec.	0.2 µ sec.	
Signal Falltime (90% to 10%)	1.0 µ sec.	0.1 µ sec.	
Useful Frequency Range	0 to 100 KHz	0 to 100 KHz	0 to 100 KHz
Max. Sink Current	4.0 ma	16 ma	40 ma
Max. Source Current	0.5 ma	1.0 ma	40 ma
Output Device	LM339 (open collector with 3.6k ohm pull-up resistor)	7404	MC3487
Resolution	Up to 2,540 ppr	Up to 2,540 ppr	Up to ~~2,540~~ 100 ppr

Output Waveforms



Notes:

1. Rotation is ccw viewed from encoder cover end
2. Symmetry (S): 180° ±10°, adjustable by internal potentiometer
3. Quadrature (Q): 90° ±25°, adjustable by photohead movement
4. Complementary output signals ($\bar{A}$, $\bar{B}$, and $\bar{M}$) are provided on CO and LD versions
5. Marker (zero index) pulse width (M): 90° to 270°, adjustable by internal potentiometer (random position)
6. Channels B and $\bar{B}$ omitted on single channel units

Tel: (513) 898-3621
Fax: (513) 898-8624
Lucas Ledex

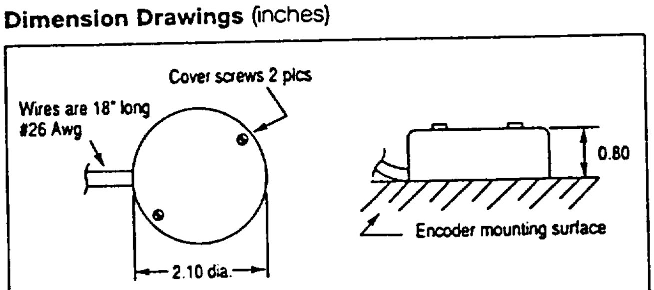
K3 Series

Incremental Encoder
Modular
Resolution to 2,540 ppr

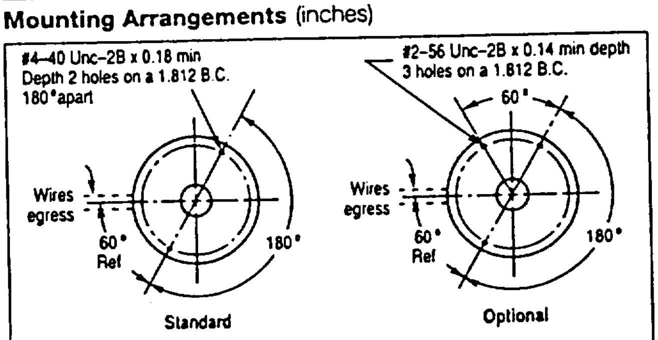
Mechanical Specifications (inches)

Encoder	
Inertia of Hub/Disk Assembly	1.0×10^{-4} oz-in-sec^2 max.
Disk Material	Metal deposition on glass, photoemulsion on plastic, or etched metal
Air Gap, Disk to Photohead Stator	0.010 for 50–250 ppr 0.007 for 251–799 ppr 0.005 for 800–1,200 ppr 0.003 for 1,201–2,540 ppr
Operating Temperature	0° to +70° C
Storage Temperature	-20° to +80°C
Humidity	95% RH non-condensing
Motor	
Mounting Holes	(2) #4-40 x 0.18 deep min. on a 1.812 dia. B.C. or (3) #2-56 x 0.14 deep min. tapped holes spaced on a 1.812 dia. B.C.
Shaft Diameter Tolerance	Nominal dia. −0.0003 to −0.0005. Example: 3/8" nom. (0.3750) = 0.3745 to 0.3747
Standard Shaft Diameters	See "How to Order"
Shaft Length	0.67/0.73 (for closed cover)
Shaft Runout	0.001 TIR max. at end of shaft
Perpendicularity	0.001 TIR max. shaft to mounting surface
Shaft Axial Movement	0.001 max. toward end of motor opposite from encoder mounting surface

Dimension Drawings (inches)



Mounting Arrangements (inches)



Note: Mounting holes must be located within ± 0.005 of true position with respect to shaft center line.

4

Electrical Connections

Output Configuration	SE or 7404	CO or LD
Wire Color	**Function**	**Function**
Yellow	Output A	Output A
Yellow/White		Output $\bar{A}$
Blue	Output B	Output B
Blue/White		Output $\bar{B}$
Orange	Output M	Output M
Red	+V	+V
Black	Ground	Ground
Orange/White		Output $\bar{M}$

Standard Pulses Per Revolution (ppr)

50	200	360	900	1,500*
[redacted]	240	400	1,000	2,000*
104	250	500	1,024	2,500*
120	254	600	1,200	2,540*
125	256	720	1,250	
180	300	800	1,270	

Others are available — consult factory
Factory installation of encoder is recommended

How to Order—shaded features available from stock.

Construct a model number per the example below:

Example: K3DM–500–5SE–4A–M 100

K3 | DM – 500 – 5 | SE – 4 | A – M

No. of channels
SO: Single channel
SM: With marker
DO: Dual channel
DM: With marker

Pulses per revolution
Select from table above

Supply voltage
Specify 5 or 12 VDC

Output driver
SE: Single ended square wave
7404: Buffered square wave
CO: Complementary TTL outputs
LD: Line driver

Shaft (bore) diameter

English	Metric
4: 1/4"	M6: 6mm
5: 5/16	M8: 8mm
6: 3/8"	M10: 10mm
8: 1/2"	M12: 12mm

Others available: consult factory.

Cover configuration
A: Closed back
B: Hole for through shaft

Optional Features
Blank: None
M: 3 hole mounting (#2-56 screws)

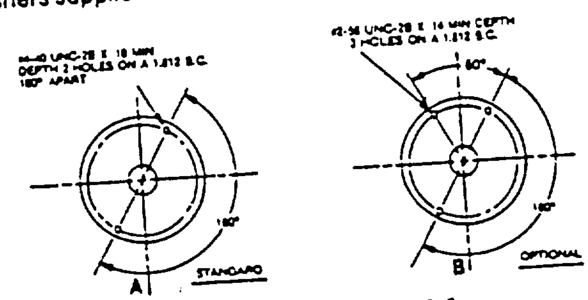
Installation Instructions
K3 Series Modular Encoder
(TTL Version)

1. MOUNTING ARRANGEMENT

Refer to Figure 1A for mounting surface arrangement. Note that (2) #4-40 X .18 deep tapped holes are called for. The two tapped holes are used to mount the encoder photohead assembly to the motor surface with #4-40 X ⁵/₁₆ fillister head screws.

Two #2-56 X ¼ pan head screws are used to hold down the encoder cover. These screws thread into the photohead assembly at the places indicated.

Note that an alternative mounting arrangement is possible. The two #4-40 mounting screws may be replaced by three #2-56 X ⁵/₁₆ fillister head screws located at the positions indicated in Figure 1B. In this case note that the two holes that are diametrically opposite in the encoder housing will have oversize clearance for #2-56 hardware. This clearance is reduced to appropriate size using the two fibre shoulder washers supplied with the unit.



NOTE:
MOUNTING HOLES MUST BE LOCATED WITHIN ±.005 OF TRUE POSITION WITH RESPECT TO SHAFT CENTER LINE.

Figure 1 - Mounting Arrangements

2. INSTALLATION PROCEDURE

Step 1 - Install Rotor/Hub Assembly

Slide rotor/hub assembly onto the shaft. A close sliding fit is desired. Excessive looseness can cause high rotor wobble. Slide the assembly to a position which will allow the rotor to enter the photothead gap with safe clearance both above and below the rotor disc. The bottom of the disc surface will be approximately ¼" above the encoder mounting surface. Lightly tighten one hub set screw.

Note that the #4-48 hub set screws are much easier to handle if the hex wrench is held in a pin vise.

Step 2 - Install Photohead Assembly

Slide the photohead assembly along the motor mounting surface so that the disc enters the photohead gap. Find the mounting hole locations and drop in the mounting screws. Be sure there is safe clearance above and below the disc. **Tighten the mounting screws enough to get a firm, secure hold down. However, avoid excessive overtightening as this could crush the plastic housing and damage the encoder.**

Loosen the hub set screw and set the working air gap using the plastic shim that is provided.

Table 1 - Air Gap Setting

Shim Color	Air Gap	Resolution
Brown	.010"	50- 250 PPR
Clear (Matte)	.0075"	251- 799 PPR
Blue	.005"	800-1200 PPR

Insert the shim into the housing opening at the rear outside wall which is opposite to the horseshoe opening.

Drop the disc so that there is light contact sandwiching shim between the bottom surface of the rotor and the stat

Tighten the set screws and pull out the shim.

Step 3 - Electrical Connections

Table 2 - Electrical Connections

Wire Color	Funtion
Yellow	Output A
Blue	Output B
Orange	Output M
Red	-V
Black	Ground

Step 4 - Test Encoder

Run the shaft at the desired speed and functionally tes encoder. The output signals' dc balance (symmetry) anc quadrature phase relationship are factory set and shoulc ordinarily not require adjustment. However, should finer be desired continue as follows: Adjustment pots are accessible on the photohead printed circuit board whic allow a fine trim of the symmetry of the output signals. S figure 3. The phase relationship of the output signals ca changed by movement of the photohead assembly on t mounting surface within the range of clearance arounc mounting hardware. Both symmetry and phase adjustm described above can only be achieved while observing output waveforms with an oscilliscope. See Figure 2.

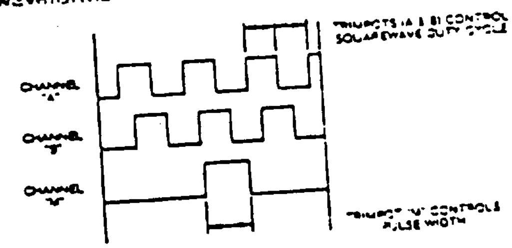


Figure 2 - Waveform Characteristics (CCW rotation viewed from encoder end)

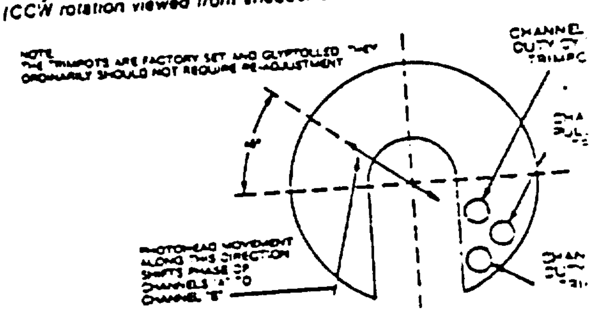


Figure 3 - Photohead Board Pot Layout

CAUTION!

Always apply downward pressure on the photohead assembly while attempting phase adjustment in ord avoid rubbing the disc against the stator.

Step 5 - Install Cover

Install cover over encoder using (2) #2-56 screws **Do not overtighten cover screws.**

Lucas Ledex

Lucas Ledex Inc.
301 Scholz Drive, P. O. Box 427
Vandalia, Ohio 45377-0427 USA

Phone: 513-898-3621
TWX, Telex 6874241, 6874243
FAX: 513-898-8624

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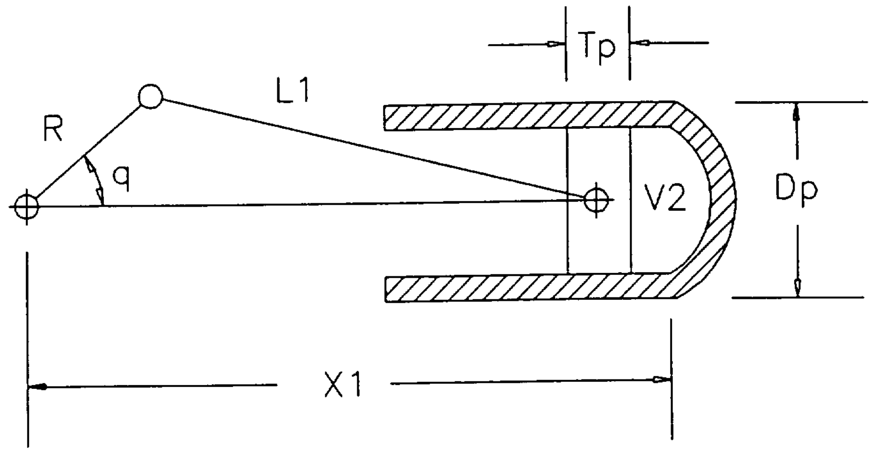
APPENDIX L

CALCULATIONS FOR VOLUME AS A FUNCTION OF CRANK ANGLE:



$$V_2 = \frac{\pi Dp^2}{4} \left\{ X_1 - Tp - R\cos(q) - L_1 \cos\left\{ \sin^{-1}\left[(R/L_1)\sin(q) \right] \right\} \right\}$$

WHERE:

- R = CRANK ARM = 21mm
- $L1$ = CONNECTING ROD = 73mm
- Dp = BORE = 64mm
- q = CRANK ANGLE = 0°–360°
- $X1$ = TOP OF SWEPT VOLUME (COMBUSTION CHAMBER IS SEMI-HEMISPHERICAL)
- Tp = DISTANCE BETWEEN PIN CONNECTION & TOP OF PISTON (PISTON TOP IS NOT FLAT)

• BECAUSE OF THE GEOMETRY OF PISTON + PISTON CROWN THEIR INDIVIDUAL VALUES ARE DIFFICULT TO CALCULATE, BUT WE KNOW $(X1 - Tp)$ IS CONSTANT AND THIS VALUE CAN BE CALCULATED. THIS IS DONE ON THE FOLLOWING PAGES cont.

WE KNOW: COMPRESSION RATIO = 8.5

$@\ \theta = 180^\circ \quad PD = \frac{118 cm^3}{rev.}$ = VOLUME SWEPT FROM T.D.C. TO B.D.C.

AND $@\ \theta = 180^\circ \quad V2 = CV + PD$

WHERE $CV = \frac{PD}{CR - 1.0} = \frac{.000118 m^3}{8.5 - 1.0} = .00001573 m^3$

$\therefore V_2 = .00013373 m^3$

- PLUGGING THESE KNOWN VALUES INTO THE GENERAL EQUATION FOR VOLUME AS A FUNCTION OF CRANK ANGLE RESULTS IN:

$$X_1 - T_P = .0935699 m = \text{CONSTANT}$$

- NOW ALL VARIABLES IN THE GENERAL EQUATION HAVE BEEN DEFINED FOR THE HONDA GX-120 4 Hp. ENGINE. THESE VALUES ARE INPUT INTO THE FORTRAN PROGRAM "CRANK.FOR" WHICH FOLLOWS THESE CALCULATIONS.

```
      PROGRAM CRANK
*
***********************************************************************
*    THIS PROGRAM DETERMINES THE CRANK ANGLE AS A FUNCTION            *
*    OF CYLINDER VOLUME FOR A HONDA 4-HP ENGINE, MODEL: GX-120.       *
*    THE FOLLOWING VARIABLES ARE DEFINED AS:                          *
*                                                                     *
*                                                                     *
*                                                                     *
*                                                                     *
*    X1 = TOP OF SWEPT VOLUME (COMB. CHAMBER IS SEMI-HEMISPHERICAL)   *
*    Tp = PISTON CROWN (TOP) IS NOT FLAT                              *
*         BUT    (X1-Tp)  = CONSTANT                                  *
*    R = 21mm    L1 = 73mm    Dp = BORE = 64mm    q = 0-360 DEGREES   *
*                                                                     *
*    THESE VALUES ARE USE TO CALCULATE THE PISTON VOLUME AS A         *
*    FUNCTION OF CRANK ANGLE USING THE FOLLOWING GENERAL FORMULA:     *
*                                                                     *
```

$$V2 = \frac{\pi Dp^2}{4} \left\{ X1 - Tp - R\cos(q) - L1\cos\left\{\sin^{-1}\left[(R/L1)\sin(q)\right]\right\}\right\}$$

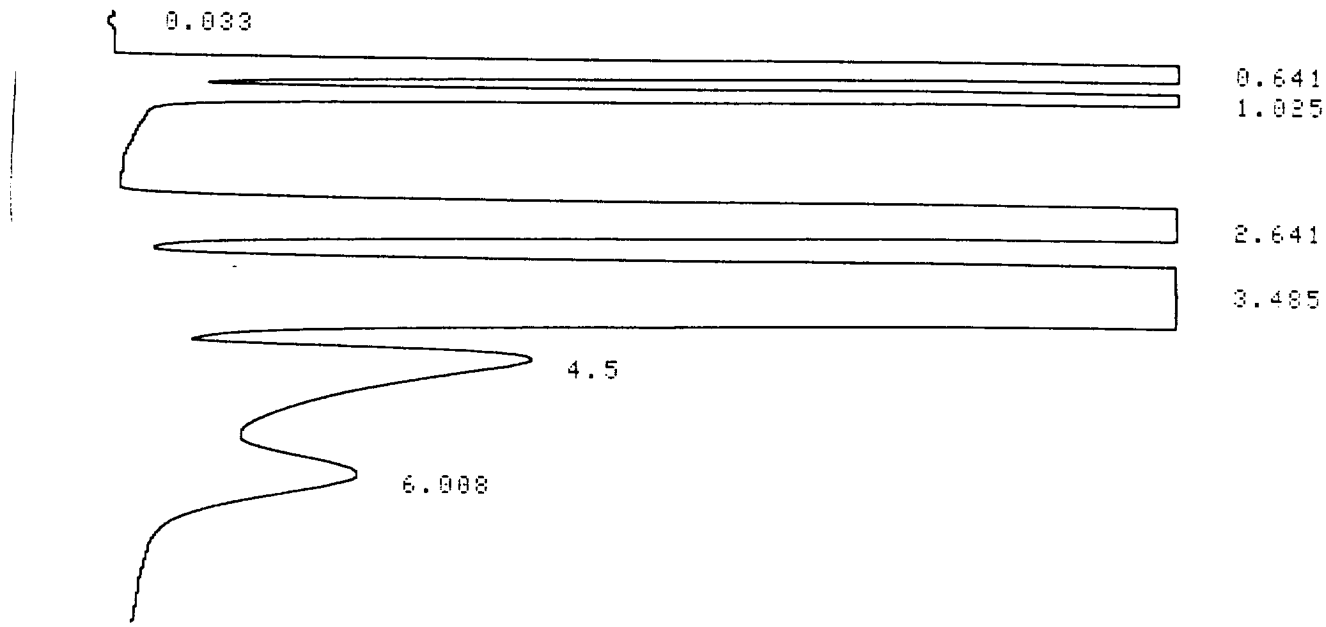
```
*                                                                     *
***********************************************************************
*
      REAL R,L1,Dp,CR,q,CV,X1Tp,Pie,A,B,C,D,E,V2,V2180
*
*     WHERE CR = COMPRESSION RATIO
*           CV = CLEARANCE VOLUME
*           X1Tp = X1-Tp  (SEE ATTACHED CALCULATIONS)
*           PD = PISTON DISPLACEMENT
*
*     INITILIZATION OF VARIABLES:
*
      R=0.021
      L1=0.073
      Dp=0.064
      CR=8.5
      PD = 0.000118
      Pie=3.14159265359
      q=0.0
*
      CV=PD/(CR-1.0)
      V2180=CV+PD
      X1Tp=((V2180*4.0)/(Pie*Dp**2))-R+L1
*
*
*     OPEN OUTPUT DATA FILE = "CRANK.OUT"
*
      OPEN(UNIT=13,FILE='CRANK.OUT',STATUS='OLD')
*
      DO 10 I=0,100
        QQ=(PIE/180)*Q
        A=(Pie*(Dp**2))/4.0
        A1=SIN(QQ)
        B=(R/L1)*A1
        C=ASIN(B)
        D=L1*COS(C)
        E=X1TP-(R*COS(QQ))-D
        V2=A*E
```

```
*
      WRITE(13,20)QQ,q,V2
 20   FORMAT(F15.9,3X,F7.3,3X,F15.9)
      q=q+3.6
 10   CONTINUE
*
      END
```

CRANK ANGLE (RADIANS)	CRANK ANGLE (DEGREES)	VOLUME (m3)
.000000000	.000	-.000001380
.062831860	3.600	-.000001209
.125663700	7.200	-.000000695
.188495500	10.800	.000000158
.251327400	14.400	.000001344
.314159300	18.000	.000002856
.376991100	21.600	.000004684
.439823000	25.200	.000006818
.502654900	28.800	.000009242
.565486700	32.400	.000011943
.628318500	36.000	.000014903
.691150400	39.600	.000018105
.753982200	43.200	.000021528
.816814000	46.800	.000025152
.879645900	50.400	.000028956
.942477700	54.000	.000032916
1.005309000	57.600	.000037010
1.068141000	61.200	.000041215
1.130973000	64.800	.000045507
1.193805000	68.400	.000049863
1.256637000	72.000	.000054260
1.319469000	75.600	.000058676
1.382300000	79.200	.000063089
1.445132000	82.800	.000067477
1.507964000	86.400	.000071821
1.570796000	90.000	.000076103
1.633628000	93.600	.000080305
1.696460000	97.200	.000084411
1.759291000	100.800	.000088406
1.822123000	104.400	.000092277
1.884955000	108.000	.000096013
1.947787000	111.600	.000099602
2.010619000	115.200	.000103036
2.073451000	118.800	.000106307
2.136282000	122.400	.000109408
2.199114000	126.000	.000112334
2.261946000	129.600	.000115080
2.324778000	133.200	.000117644
2.387610000	136.800	.000120022
2.450442000	140.400	.000122212
2.513274000	144.000	.000124213
2.576106000	147.600	.000126023
2.638938000	151.200	.000127643
2.701770000	154.800	.000129072
2.764602000	158.400	.000130310
2.827434000	162.000	.000131357
2.890266000	165.600	.000132213
2.953098000	169.200	.000132878
3.015930000	172.800	.000133353
3.078762000	176.400	.000133638
3.141593000	180.000	.000133733
3.204426000	183.600	.000133638
3.267257000	187.200	.000133353
3.330089000	190.800	.000132878
3.392921000	194.400	.000132213
3.455753000	198.000	.000131357
3.518585000	201.600	.000130310

3.581417000	205.200	.000129072
3.644249000	208.800	.000127643
3.707081000	212.400	.000126023
3.769913000	216.000	.000124213
3.832745000	219.600	.000122212
3.895577000	223.200	.000120022
3.958409000	226.800	.000117644
4.021241000	230.400	.000115080
4.084073000	234.000	.000112334
4.146905000	237.600	.000109408
4.209737000	241.200	.000106306
4.272569000	244.800	.000103036
4.335401000	248.400	.000099602
4.398233000	252.000	.000096013
4.461065000	255.600	.000092277
4.523896000	259.200	.000088406
4.586729000	262.800	.000084411
4.649560000	266.400	.000080305
4.712392000	270.000	.000076103
4.775224000	273.600	.000071821
4.838056000	277.200	.000067477
4.900888000	280.800	.000063088
4.963720000	284.400	.000058676
5.026552000	288.000	.000054260
5.089384000	291.600	.000049863
5.152216000	295.200	.000045507
5.215048000	298.800	.000041215
5.277880000	302.400	.000037010
5.340712000	306.000	.000032916
5.403544000	309.600	.000028956
5.466376000	313.200	.000025152
5.529208000	316.800	.000021528
5.592040000	320.400	.000018105
5.654872000	324.000	.000014903
5.717704000	327.600	.000011943
5.780536000	331.200	.000009242
5.843368000	334.800	.000006817
5.906199000	338.400	.000004684
5.969031000	342.000	.000002856
6.031864000	345.600	.000001344
6.094696000	349.200	.000000158
6.157527000	352.800	-.000000695
6.220359000	356.400	-.000001209
6.283191000	360.000	-.000001380

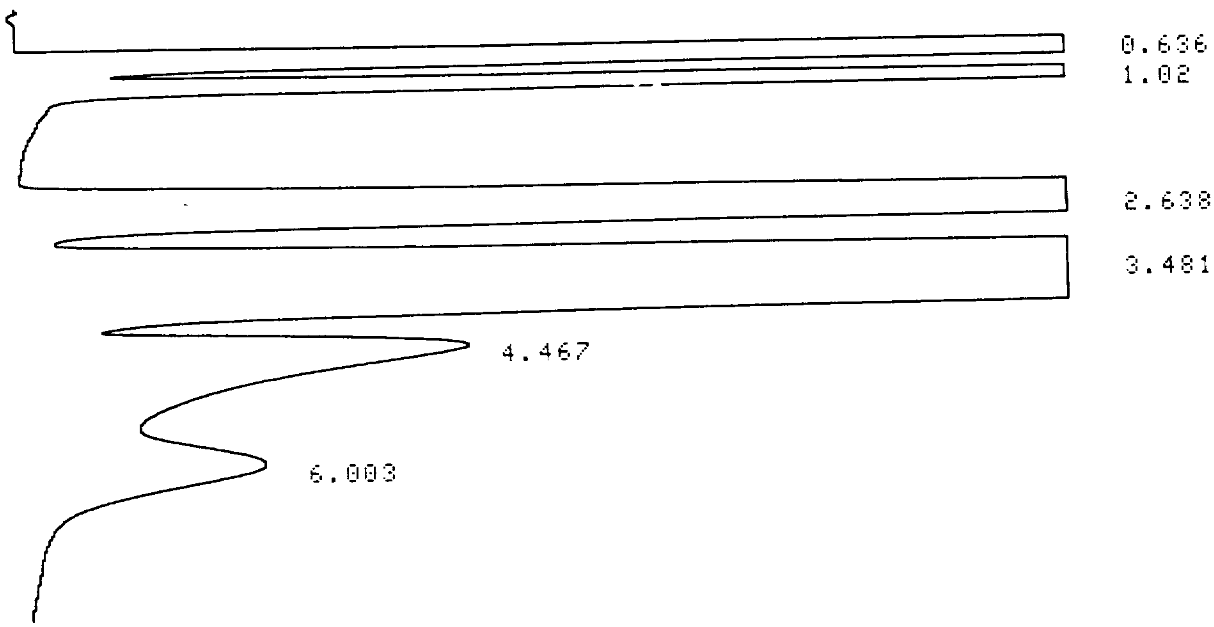
APPENDIX M



CHROMATOGRAM 1 MEMORIZED

C-R5A CHROMATOPAC
CHANNEL NO 1 FILE 2
SAMPLE NO 0 METHOD 42
REPORT NO 148

PKNO	TIME	AREA	MK	IDNO	CONC	NAME
1	0.033	16				
2	0.641	1321249				
3	1.025	85162	V	2	3.3591	CO2
4	2.641	258931		3	12.2814	O2
5	3.485	1833078	SV	4	83.189	N2
6	4.5	12918	T	5	0.7482	H2O
7	6.008	7934	TV	6	0.4223	Meth2
	TOTAL	3519287			100	

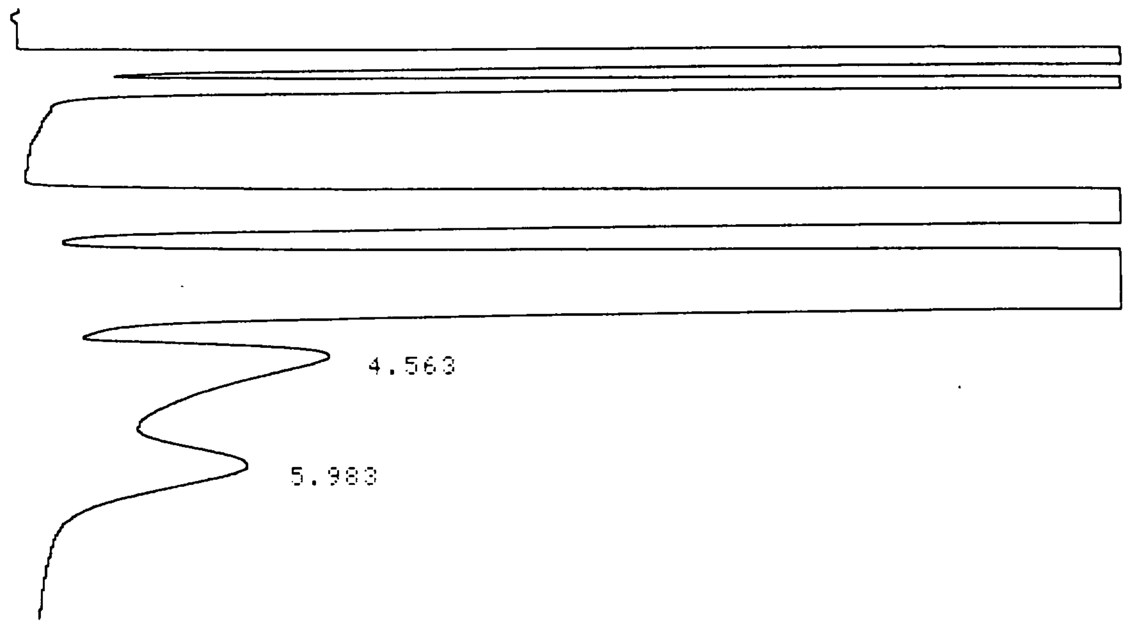


CHROMATOGRAM 1 MEMORIZED

C-R5A CHROMATOPAC
CHANNEL NO 1
SAMPLE NO 0
REPORT NO 150

FILE 2
METHOD 42

PKNO	TIME	AREA	MK	IDNO	CONC	NAME
1	0.636	1310826				
2	1.02	86190	V	2	3.4222	CO2
3	2.638	250386		3	11.9548	O2
4	3.481	1825915	SV	4	83.4129	N2
5	4.467	13495	T	5	0.7869	H2O
6	6.003	7901	TV	6	0.4232	Meth2
	TOTAL	3494711			100	



CHROMATOGRAM 1 MEMORIZED

C-R5A CHROMATOPAC
CHANNEL NO 1 FILE 2
SAMPLE NO 0 METHOD 42
REPORT NO 151

PKNO	TIME	AREA	MK	IDNO	CONC	NAME
1	0.632	1313914				
2	1.017	76417	V	2	3.0526	CO2
3	2.628	272484		3	13.0888	O2
4	3.473	1803195	SV	4	82.8749	N2
5	4.563	9720	T	5	0.5702	H2O
6	5.983	7673	TV	6	0.4135	Meth2
	TOTAL	3483402			100	

Untitled Data #1 Mon, Apr 12, 1993 11:26 AM

	CO2	O2	N2	H2O	CH4	
1	76417.00	272484.0	1803195.0	9720.00	7673.000	
2	86190.00	250386.0	1825915.0	13495.00	7901.000	
3	85162.00	258931.0	1833078.0	12918.00	7934.000	
4						
5						
6	1588.71	6812.1	43132.4	296.75	215.228	51748.000
7	1791.89	6259.6	43675.9	412.00	221.623	51950.000
8	1770.52	6473.3	43847.2	394.39	222.549	52708.000
9						
10						
11	3.07	13.2	83.4		0.416	
12	3.45	12.0	84.1		0.427	
13	3.36	12.3	83.2		0.422	

APPENDIX N

```
*        PROGRAMMER:  SCOTT A. HOOVER
*              DATE:  SPRING 1993
*            COURSE:  MEM434/SENIOR DESIGN PROJECT
*           ADVISOR:  DR. C.P. BRITCHER
*
*        'TEAM Med':  MARS ENGINE DESIGN
*
*
      PROGRAM MARS
*
*
*     configuration functions:
      INTEGER*2 LPINIT,LPSB,LPST,LPTERM
*
*     analog input functions:
      INTEGER*2 LPAV,LPAOT,LPSETA,LPADS,LPBAD,LPCAD,LPTAD,LPWAD,LPSAD
*     analog output functions:
      INTEGER*2 LPDV,LPSETD,LPDAS,LPBDA,LPCDA,LPTDA,LPWDA,LPSDA
*     digital I/O functions:
      INTEGER*2 LPEFO,LPEFI,LPODV,LPIDV
*     clock functions:
      INTEGER*2 LPRCF,LPSCF,LPDSC,LPESC
*     data manipulations:
      INTEGER*2 LPMV,LPGV,LPMT,LPMC,LPVTD,LPDTV,LPATV,LPVTA
*     error processor functions;
      INTEGER*2 LPSECW,LPGEC
*
      INTEGER*2 STATUS,TC,CHAN
      INTEGER*2 STRTCHN,ENDCHN,GAIN
      INTEGER*2 COUNT,TIMING,ARRAY(1000)
      INTEGER*2 PORT,MASK,VALUE,ARAY(1000)
      REAL*4 FREQ,TIME,PRESS
      REAL*4 DEG,VOLTS
*
*     lpclab subroutines - fortran definition files
*
      OPEN(UNIT=13,FILE='DATA.O',STATUS='OLD')
      TIMING = 0
      STRTCHN = 1
      ENDCHN = 1
      GAIN = 1
      TIME = 0
      PRESS = 0
      PRINT*,'INPUT THE FREQUENCY FOR THIS RUN:'
      READ*, FREQ
      PRINT*,'INPUT THE NUMBER OF COUNTS'
      READ*, COUNT
      PRINT*,'INPUT THE NUMBER OF (D/A) VALUES TO BE READ FROM ENCODER'
      READ*, VALUE
*
      CHAN= 4
      TC=75
      PORT = 0
      MASK = 11
*
      STATUS = LPINIT()
      STATUS = LPSB(1)
      STATUS = LPST(0)
      STATUS = LPSCF(FREQ)
      STATUS = LPSETA(TIMING,STRTCHN,ENDCHN,GAIN)
```

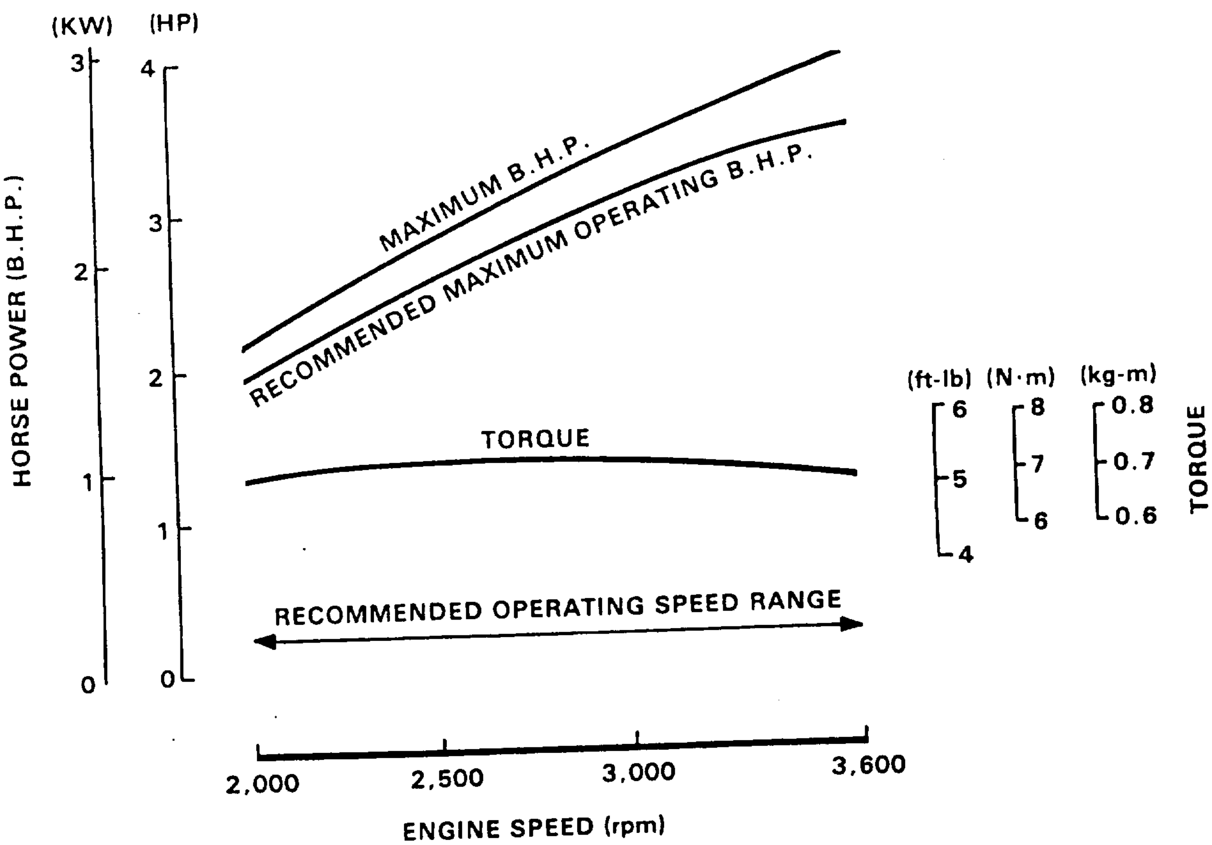
```
      STATUS = LPBAD(COUNT,ARRAY(1))
      STATUS = LPWAD(ARRAY(COUNT))
      STATUS = LPMT(TC,CHAN,DEG)
*
*     ***************************************************************
*     *              THERMOCOUPLE TEMPERATURE FOR EXHAUST             *
*     ***************************************************************
      PRINT 5
 5    FORMAT(1X,'TEMPERATURE OF THE THERMOCOUPLE (CELCIUS)')
      PRINT*,DEG
      WRITE(13,10)
 10   FORMAT(1X,'THEMOCOUPLE TYPE',3X,'CHANNEL',3X,'TEMPERATURE (C)')
      WRITE(13,*)TC,CHAN,DEG
      WRITE(13,15)
 15   FORMAT(1X,'THE FREQUENCY OF THIS RUN IS:')
      WRITE(13,*)FREQ
      WRITE(13,*)
      WRITE(13,20)
 20   FORMAT(1X,'THE NUMBER OF COUNTS:')
      WRITE(13,*) COUNT
*
*     **************************************************************
*     *              PRESSURE FOR AVL PRESSURE TRANSDUCER            *
*     **************************************************************
      WRITE(13,*)
      WRITE(13,*)
      WRITE(13,25)
 25   FORMAT(5X,'VOLTS',10X,'DIGITAL VALUE',5X,'TIME(SEC)',10X,
     +'PRESSURE(PSIG)')
      DO 100 I=1,COUNT
      STATUS = LPATV(ARRAY(I),GAIN,VOLTS)
      PRESS=(VOLTS*10*1.0133E5)/6894.76
      TIME=TIME + (1/FREQ)
      WRITE(13,30)VOLTS,ARRAY(I),TIME,PRESS
 30   FORMAT(1X,E12.6,10X,I5,10X,F7.5,14X,F6.2)
 100  CONTINUE
*
*     **************************************************************
*     *                   ENCODER ANGLE PROGRAM                      *
*     **************************************************************
      WRITE(13,*)
      WRITE(13,*)
      WRITE(13,35)
 35   FORMAT(5X,'DIGITAL VALUE',5X,'ENCODER ANGLE')
      DO 200 I=1,VALUE
      STATUS = LPIDV(PORT,MASK,ARAY(I))
*      PRINT*,ARAY(I)
*      WRITE(13,40)ARAY(I)
 40   FORMAT(1X,I3)
 200  CONTINUE
      END
```

APPENDIX O

PERFORMANCE CURVES

Tests were conducted according to SAE standard No. J607a. Power curves are for standard sea level atmospheric pressure of 29.92 in. (760 mm) Hg at a temperature of 60 F (15.6 C). Power curves are of a standard test engine equipped with standard air cleaner, muffler and other power consuming devices. Power output will decrease 3.5% for each, 1,000 ft. (305 m) of elevation above sea level and 1% for each 10°F (5.6 C) rise above the standard temperature of 60 F (15.6 C). As shipped, production engines will develop not less than 90% of the "Maximum B.H.P."
After being run-in, they will develop not less than 95% of the "Maximum B.H.P.". For practical operations, the B.H.P. load and engine speed should not exceed the limit defined by the "Recommended Maximum Operating B.H.P." curve. Continuous operation should not exceed 85% of the Maximum B.H.P.

<GK120K1>



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MODIFIED DATA

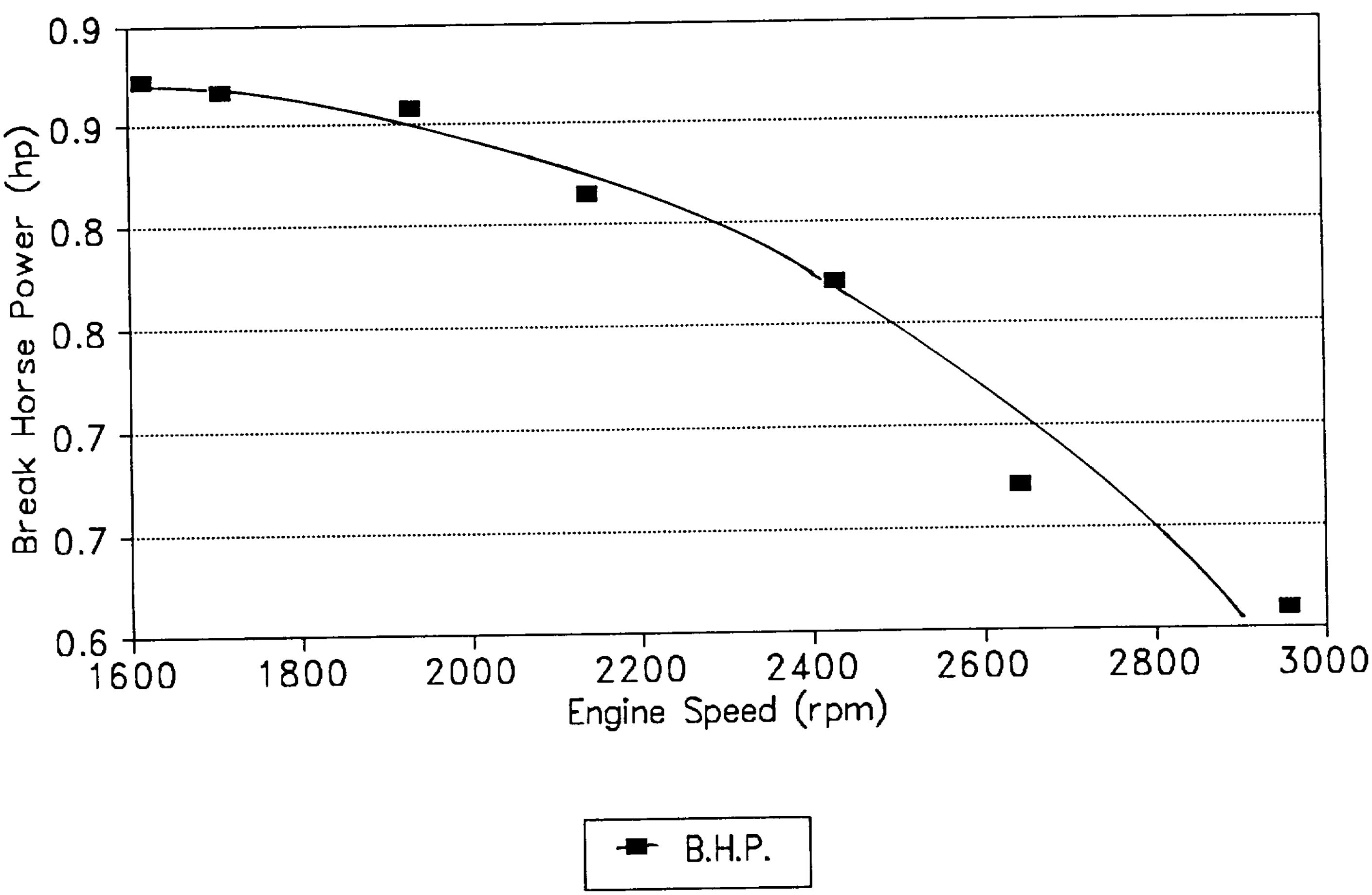
HONDA GX120 ENGINE (FULL THROTTLE)

FUEL: UNLEADED GASOLINE

RUN	N (RPM)	TORQUE (in-lbs)	TORQUE (ft-lbs)	BHP (hp)
1	2957	13	1.083	0.6097
2	2643	16	1.333	0.6708
3	2430	20	1.667	0.7713
4	2140	24	2.000	0.8149
5	1932	28	2.333	0.8582
6	1708	32	2.667	0.8673
7	1617	34	2.833	0.8722

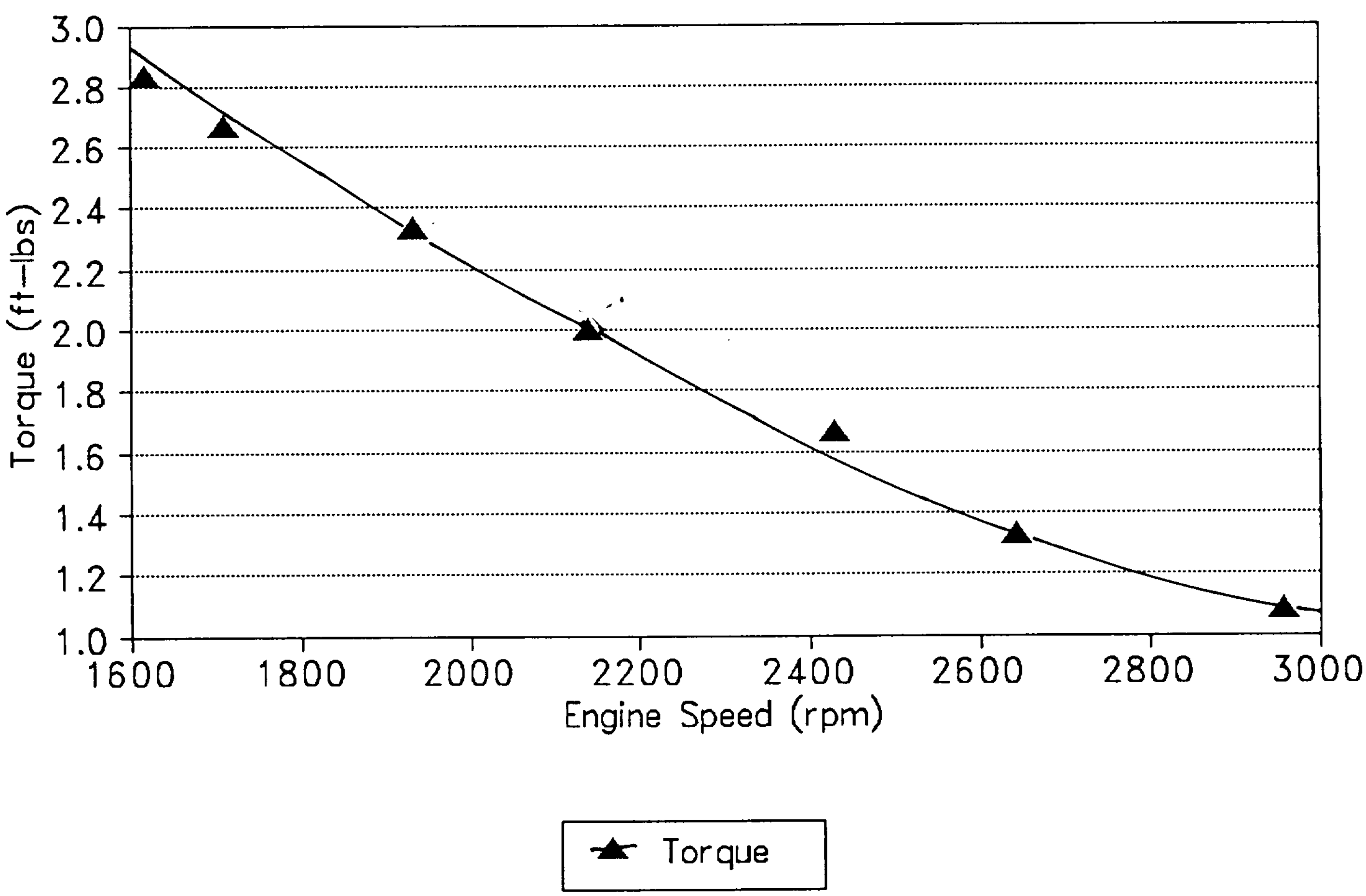
Performance Curves for Honda GX120

Unleaded Gasoline (Full Throttle)



Performance Curves for Honda GX120

Unleaded Gasoline (Full Throttle)



APPENDIX P

DATE: APRIL 16, 1993

R.P.M.: 2700
TORQUE: 20 in-lbs. (LOAD #1)

FLOWRATES: CH4: 8mm

INLET PRESSURE: <1 atm.
EXHAUST TEMPERATURE (C): 572.4749

VOLTS (volts)	DIGITAL	TIME (sec)	PRESSURE (psig)
0.87647	2407	0.002	128.81
0.34668	2190	0.004	50.95
0.13184	2102	0.006	19.38
0.06592	2075	0.008	9.69
8.00000	2055	0.010	2.51
-0.16846	1979	0.012	-24.76
-0.24414	1948	0.014	-35.88
-0.25391	1944	0.016	-37.32
-0.26367	1940	0.018	-38.75
-0.26123	1941	0.020	-38.39
-0.16846	1979	0.022	-24.76
-0.29297	1928	0.024	-43.06
-0.28809	1930	0.026	-42.34
-0.28809	1930	0.028	-42.34
-0.28809	1930	0.030	-42.34
-0.27344	1936	0.032	-40.19
-0.26367	1940	0.034	-38.75
-0.24414	1948	0.036	-35.88
-0.17578	1976	0.038	-25.83
-0.00488	2046	0.040	-0.72
0.55420	2275	0.042	81.45
1.29883	2580	0.044	190.88
0.77637	2366	0.046	114.10
0.30518	2173	0.048	44.85
0.10254	2090	0.050	15.07
0.03662	2063	0.052	5.38
-0.01221	2043	0.054	-1.79
-0.17334	1977	0.056	-25.48
-0.23193	1953	0.058	-34.09
-0.23682	1951	0.060	-34.80
-0.23438	1952	0.062	-34.45
-0.22949	1954	0.064	-33.73

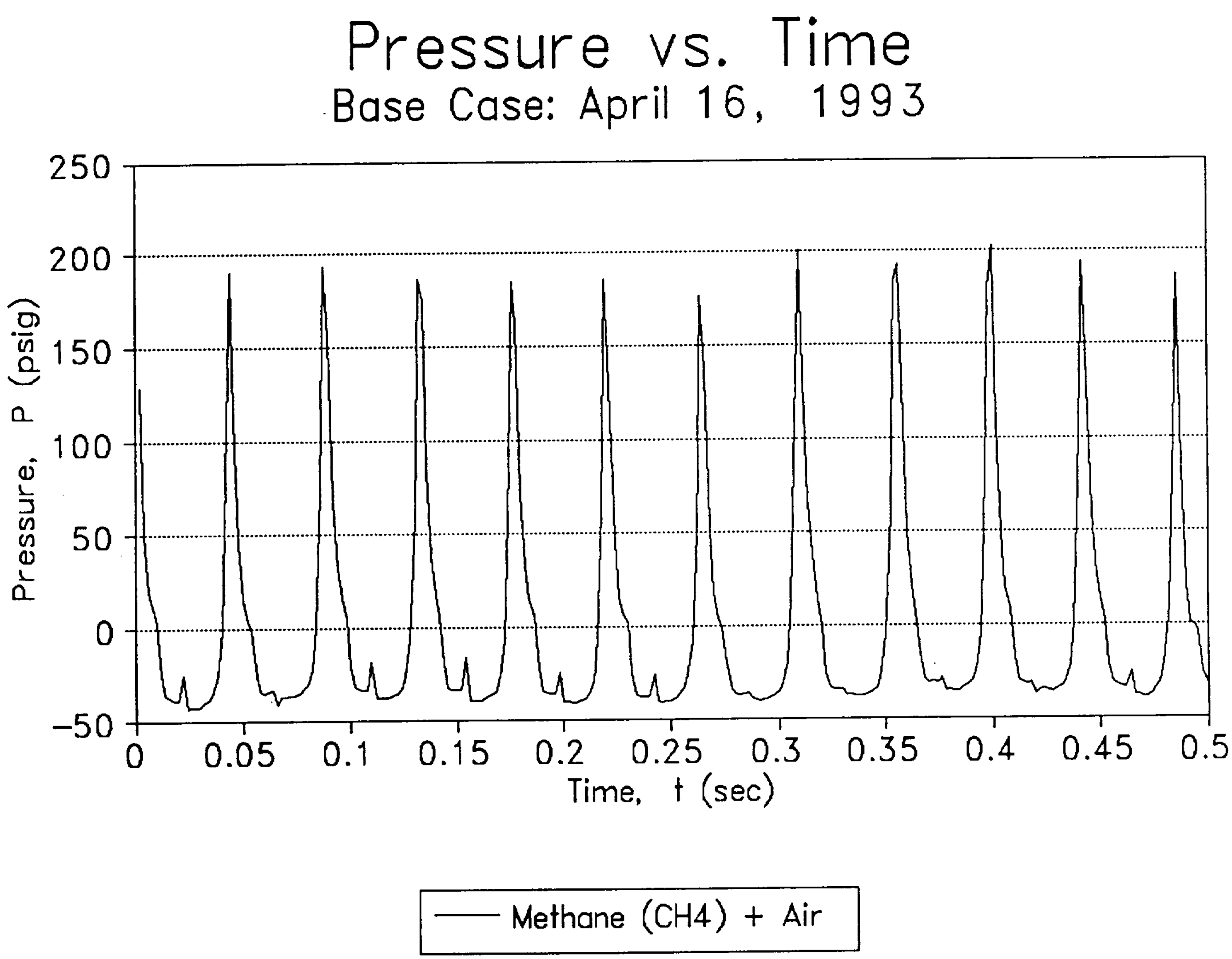
3.00000	1932	0.066	-41.62
-0.25391	1944	0.068	-37.32
-0.25147	1945	0.070	-36.96
-0.24902	1946	0.072	-36.60
-0.24902	1946	0.074	-36.60
-0.23926	1950	0.076	-35.16
-0.22461	1956	0.078	-33.01
-0.20752	1963	0.080	-30.50
-0.15625	1984	0.082	-22.96
0.00244	2049	0.084	0.36
0.49561	2251	0.086	72.84
1.31836	2588	0.088	193.75
1.05957	2482	0.090	155.72
0.46387	2238	0.092	68.17
0.21729	2137	0.094	31.93
0.10742	2092	0.096	15.79
0.03418	2062	0.098	5.02
-0.14160	1990	0.100	-20.81
-0.21484	1960	0.102	-31.57
-0.22217	1957	0.104	-32.65
-0.22949	1954	0.106	-33.73
-0.22705	1955	0.108	-33.37
-0.12451	1997	0.110	-18.30
-0.25635	1943	0.112	-37.67
-0.25635	1943	0.114	-37.67
-0.25635	1943	0.116	-37.67
-0.25635	1943	0.118	-37.67
-0.24902	1946	0.120	-36.60
-0.24170	1949	0.122	-35.52
-0.22461	1956	0.124	-33.01
-0.17578	1976	0.126	-25.83
-0.03906	2032	0.128	-5.74
0.39307	2209	0.130	57.77
1.26709	2567	0.132	186.22
1.18896	2535	0.134	174.74
0.57129	2282	0.136	83.96
0.25635	2153	0.138	37.67
0.11475	2095	0.140	16.86
0.03906	2064	0.142	5.74
-0.13184	1994	0.144	-19.38
-0.21973	1958	0.146	-32.29
-0.22949	1954	0.148	-33.73
-0.22949	1954	0.150	-33.73
-0.22949	1954	0.152	-33.73
-0.11231	2002	0.154	-16.51
-0.27100	1937	0.156	-39.83

-0.26611	1939	0.158	-39.11
-0.26611	1939	0.160	-39.11
-0.26856	1938	0.162	-39.47
-0.25879	1942	0.164	-38.03
-0.24902	1946	0.166	-36.60
-0.23926	1950	0.168	-35.16
-0.18066	1974	0.170	-26.55
-0.04395	2030	0.172	-6.46
0.39307	2209	0.174	57.77
1.25732	2563	0.176	184.78
1.10352	2500	0.178	162.18
0.48340	2246	0.180	71.04
0.22217	2139	0.182	32.65
0.10254	2090	0.184	15.07
0.03906	2064	0.186	5.74
-0.14893	1987	0.188	-21.89
-0.23193	1953	0.190	-34.09
-0.23926	1950	0.192	-35.16
-0.24414	1948	0.194	-35.88
-0.24170	1949	0.196	-35.52
-0.16357	1981	0.198	-24.04
-0.27344	1936	0.200	-40.19
-0.27588	1935	0.202	-40.55
-0.27832	1934	0.204	-40.90
-0.27832	1934	0.206	-40.90
-0.26856	1938	0.208	-39.47
-0.26123	1941	0.210	-38.39
-0.24170	1949	0.212	-35.52
-0.19531	1968	0.214	-28.70
-0.05127	2027	0.216	-7.53
0.42481	2222	0.218	62.43
1.26221	2565	0.220	185.50
0.87891	2408	0.222	129.17
0.31006	2175	0.224	45.57
0.10010	2089	0.226	14.71
0.03906	2064	0.228	5.74
0.01221	2053	0.230	1.79
-0.17090	1978	0.232	-25.12
-0.24902	1946	0.234	-36.60
-0.25635	1943	0.236	-37.67
-0.25635	1943	0.238	-37.67
-0.25635	1943	0.240	-37.67
-0.17578	1976	0.242	-25.83
-0.27344	1936	0.244	-40.19
-0.27832	1934	0.246	-40.90
-0.27588	1935	0.248	-40.55

-0.27588	1935	0.250	-40.55
-0.26123	1941	0.252	-38.39
-0.24902	1946	0.254	-36.60
-0.22949	1954	0.256	-33.73
-0.18066	1974	0.258	-26.55
-0.05615	2025	0.260	-8.25
0.34180	2188	0.262	50.23
1.20361	2541	0.264	176.89
0.92773	2428	0.266	136.35
0.35645	2194	0.268	52.39
0.11719	2096	0.270	17.22
0.02930	2060	0.272	4.31
-0.00488	2046	0.274	-0.72
-0.12940	1995	0.276	-19.02
-0.23438	1952	0.278	-34.45
-0.24902	1946	0.280	-36.60
-0.25391	1944	0.282	-37.32
-0.24902	1946	0.284	-36.60
-0.24170	1949	0.286	-35.52
-0.26123	1941	0.288	-38.39
-0.27100	1937	0.290	-39.83
-0.27344	1936	0.292	-40.19
-0.26611	1939	0.294	-39.11
-0.26123	1941	0.296	-38.39
-0.25147	1945	0.298	-36.96
-0.23926	1950	0.300	-35.16
-0.20996	1962	0.302	-30.86
-0.13428	1993	0.304	-19.73
0.09033	2085	0.306	13.28
0.75195	2356	0.308	110.51
1.36719	2608	0.310	200.93
0.90820	2420	0.312	133.48
0.44190	2229	0.314	64.94
0.21240	2135	0.316	31.22
0.09521	2087	0.318	13.99
-0.00488	2046	0.320	-0.72
-0.17334	1977	0.322	-25.48
-0.22461	1956	0.324	-33.01
-0.23438	1952	0.326	-34.45
-0.23193	1953	0.328	-34.09
-0.23438	1952	0.330	-34.45
-0.25147	1945	0.332	-36.96
-0.25391	1944	0.334	-37.32
-0.25879	1942	0.336	-38.03
-0.25879	1942	0.338	-38.03
-0.25635	1943	0.340	-37.67

-0.24902	1946	0.342	-36.60
-0.23926	1950	0.344	-35.16
-0.22705	1955	0.346	-33.37
-0.17090	1978	0.348	-25.12
-0.03418	2034	0.350	-5.02
0.39795	2211	0.352	58.49
1.25488	2562	0.354	184.43
1.31348	2586	0.356	193.04
0.73242	2348	0.358	107.64
0.33203	2184	0.360	48.80
0.13672	2104	0.362	20.09
0.04150	2065	0.364	6.10
-0.10498	2005	0.366	-15.43
-0.19531	1968	0.368	-28.70
-0.20752	1963	0.370	-30.50
-0.20508	1964	0.372	-30.14
-0.20996	1962	0.374	-30.86
-0.19043	1970	0.376	-27.99
-0.23682	1951	0.378	-34.80
-0.23438	1952	0.380	-34.45
-0.23926	1950	0.382	-35.16
-0.23926	1950	0.384	-35.16
-0.22949	1954	0.386	-33.73
-0.21729	1959	0.388	-31.93
-0.20020	1966	0.390	-29.42
-0.15869	1983	0.392	-23.32
-0.03662	2033	0.394	-5.38
0.34912	2191	0.396	51.31
1.22803	2551	0.398	180.48
1.38184	2614	0.400	203.08
0.72266	2344	0.402	106.21
0.32715	2182	0.404	48.08
0.13916	2105	0.406	20.45
0.05371	2070	0.408	7.89
-0.11475	2001	0.410	-16.86
-0.20020	1966	0.412	-29.42
-0.20752	1963	0.414	-30.50
-0.21240	1961	0.416	-31.22
-0.20996	1962	0.418	-30.86
-0.25147	1945	0.420	-36.96
-0.23926	1950	0.422	-35.16
-0.23193	1953	0.424	-34.09
-0.23682	1951	0.426	-34.80
-0.24170	1949	0.428	-35.52
-0.23193	1953	0.430	-34.09
-0.22217	1957	0.432	-32.65

-0.20020	1966	0.434	-29.42
-0.15137	1986	0.436	-22.25
0.00977	2052	0.438	1.44
0.51758	2260	0.440	76.07
1.32080	2589	0.442	194.11
0.99121	2454	0.444	145.67
0.40283	2213	0.446	59.20
0.18066	2122	0.448	26.55
0.09766	2088	0.450	14.35
0.01465	2054	0.452	2.15
-0.14404	1989	0.454	-21.17
-0.20752	1963	0.456	-30.50
-0.21729	1959	0.458	-31.93
-0.22461	1956	0.460	-33.01
-0.22705	1955	0.462	-33.37
-0.16846	1979	0.464	-24.76
-0.25635	1943	0.466	-37.67
-0.25879	1942	0.468	-38.03
-0.26123	1941	0.470	-38.39
-0.26123	1941	0.472	-38.39
-0.25147	1945	0.474	-36.96
-0.23438	1952	0.476	-34.45
-0.20996	1962	0.478	-30.86
-0.14160	1990	0.480	-20.81
0.06104	2073	0.482	8.97
0.70313	2336	0.484	103.34
1.27441	2570	0.486	187.30
0.56641	2280	0.488	83.24
0.13916	2105	0.490	20.45
0.00977	2052	0.492	1.44
-0.00732	2045	0.494	-1.08
-0.03174	2035	0.496	-4.66
-0.17334	1977	0.498	-25.48
-0.21973	1958	0.500	-32.29



Pressure vs. Time
Base Case: April 16, 1993
250
200
150
100
50
0
-50
Pressure, P (psig)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Time, t (sec)
Methane (CH4) + Air

DATE: APRIL 16, 1993

R.P.M.: 2700
TORQUE: 20 in-lbs. (LOAD #1)

FLOWRATES: CH4: 50mm
CO2: 50mm
O2: 30mm

INLET PRESSURE: <1 atm.
EXHAUST TEMPERATURE (C): 750.1325

VOLTS (volts)	DIGITAL	TIME (sec)	PRESSURE (psig)
-0.15869	1983	0.002	-23.32
-0.18799	1971	0.004	-27.63
-0.19287	1969	0.006	-28.35
-0.19287	1969	0.008	-28.35
-0.18066	1974	0.010	-26.55
-0.17334	1977	0.012	-25.48
-0.14893	1987	0.014	-21.89
-0.13184	1994	0.016	-19.38
-0.06836	2020	0.018	-10.05
0.11963	2097	0.020	17.58
0.61279	2299	0.022	90.06
0.86670	2403	0.024	127.38
0.72022	2343	0.026	105.85
0.53711	2268	0.028	78.94
0.31494	2177	0.030	46.29
0.19775	2129	0.032	29.06
0.03418	2062	0.034	5.02
-0.11475	2001	0.036	-16.86
-0.13428	1993	0.038	-19.73
-0.13184	1994	0.040	-19.38
-0.12451	1997	0.042	-18.30
-0.11719	2000	0.044	-17.22
-0.14893	1987	0.046	-21.89
-0.14648	1988	0.048	-21.53
-0.16602	1980	0.050	-24.40
-0.17090	1978	0.052	-25.12
-0.16846	1979	0.054	-24.76
-0.16602	1980	0.056	-24.40
-0.14893	1987	0.058	-21.89
-0.12695	1996	0.060	-18.66
-0.05859	2024	0.062	-8.61
0.14160	2106	0.064	20.81

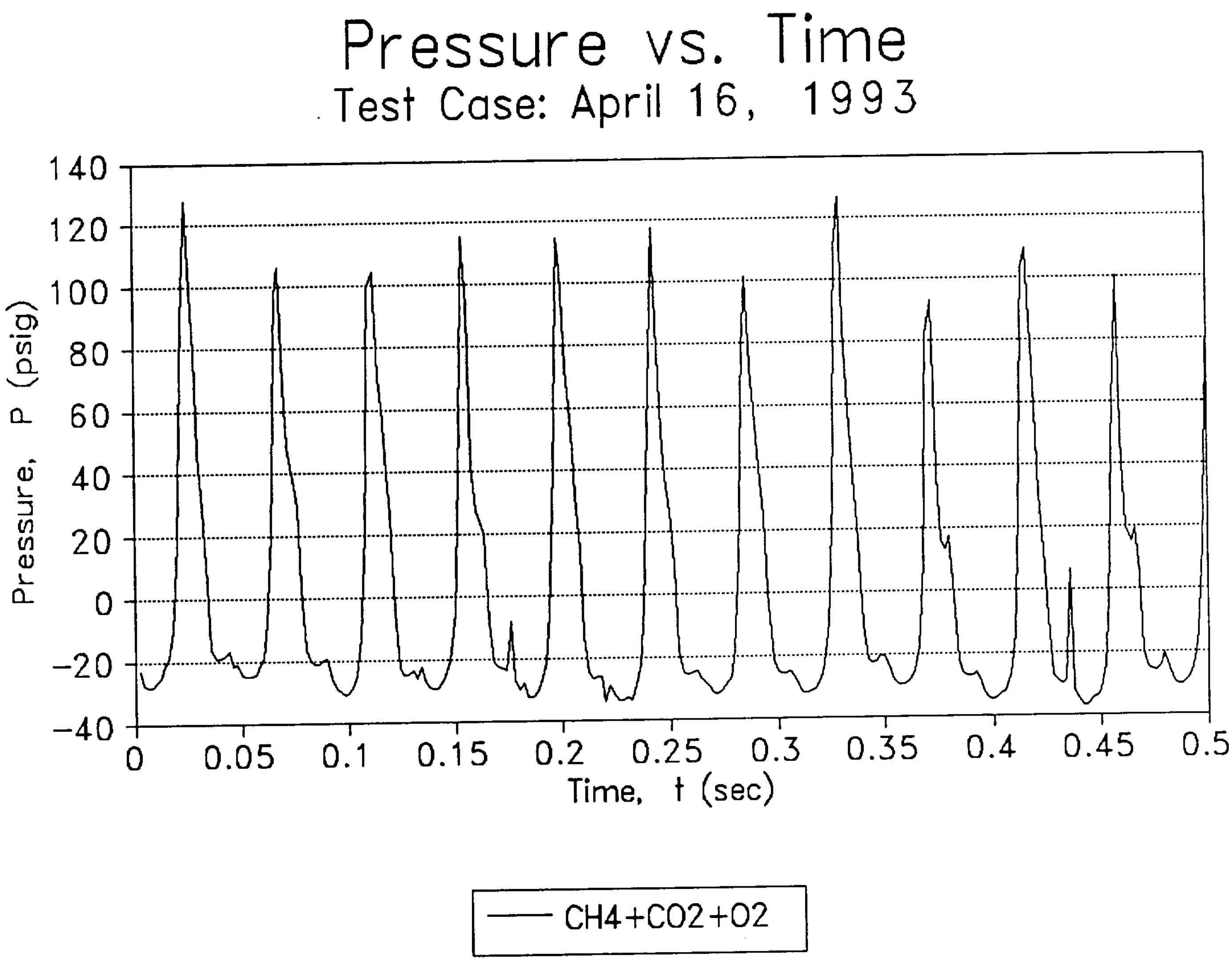
0.66650	2321	0.066	97.95
0.72266	2344	0.068	106.21
0.46143	2237	0.070	67.81
0.32959	2183	0.072	48.44
0.27100	2159	0.074	39.83
0.20020	2130	0.076	29.42
0.02686	2059	0.078	3.95
-0.11231	2002	0.080	-16.51
-0.13672	1992	0.082	-20.09
-0.14648	1988	0.084	-21.53
-0.14648	1988	0.086	-21.53
-0.13672	1992	0.088	-20.09
-0.13428	1993	0.090	-19.73
-0.17578	1976	0.092	-25.83
-0.19531	1968	0.094	-28.70
-0.20508	1964	0.096	-30.14
-0.20996	1962	0.098	-30.86
-0.20752	1963	0.100	-30.50
-0.19287	1969	0.102	-28.35
-0.16846	1979	0.104	-24.76
-0.09033	2011	0.106	-13.28
0.13916	2105	0.108	20.45
0.67871	2326	0.110	99.75
0.71045	2339	0.112	104.41
0.48096	2245	0.114	70.68
0.41504	2218	0.116	61.00
0.26856	2158	0.118	39.47
0.17578	2120	0.120	25.83
-0.03174	2035	0.122	-4.66
-0.15137	1986	0.124	-22.25
-0.16846	1979	0.126	-24.76
-0.16846	1979	0.128	-24.76
-0.16113	1982	0.130	-23.68
-0.17822	1975	0.132	-26.19
-0.15137	1986	0.134	-22.25
-0.18066	1974	0.136	-26.55
-0.19531	1968	0.138	-28.70
-0.20020	1966	0.140	-29.42
-0.20020	1966	0.142	-29.42
-0.18799	1971	0.144	-27.63
-0.16846	1979	0.146	-24.76
-0.13916	1991	0.148	-20.45
-0.03662	2033	0.150	-5.38
0.25879	2154	0.152	38.03
0.78613	2370	0.154	115.54
0.63232	2307	0.156	92.93
0.28809	2166	0.158	42.34

0.18555	2124	0.160	27.27
0.16602	2116	0.162	24.40
0.13428	2103	0.164	19.73
−0.05615	2025	0.166	−8.25
−0.14648	1988	0.168	−21.53
−0.15625	1984	0.170	−22.96
−0.15869	1983	0.172	−23.32
−0.16357	1981	0.174	−24.04
−0.05615	2025	0.176	−8.25
−0.18066	1974	0.178	−26.55
−0.20508	1964	0.180	−30.14
−0.19043	1970	0.182	−27.99
−0.21973	1958	0.184	−32.29
−0.21973	1958	0.186	−32.29
−0.20752	1963	0.188	−30.50
−0.18555	1972	0.190	−27.27
−0.14893	1987	0.192	−21.89
−0.04150	2031	0.194	−6.10
0.27100	2159	0.196	39.83
0.77881	2367	0.198	114.46
0.71045	2339	0.200	104.41
0.49316	2250	0.202	72.48
0.35645	2194	0.204	52.39
0.21484	2136	0.206	31.57
0.10010	2089	0.208	14.71
−0.09277	2010	0.210	−13.63
−0.17090	1978	0.212	−25.12
−0.18066	1974	0.214	−26.55
−0.17822	1975	0.216	−26.19
−0.17822	1975	0.218	−26.19
−0.23193	1953	0.220	−34.09
−0.19531	1968	0.222	−28.70
−0.21973	1958	0.224	−32.29
−0.22949	1954	0.226	−33.73
−0.22949	1954	0.228	−33.73
−0.22217	1957	0.230	−32.65
−0.22949	1954	0.232	−33.73
−0.19775	1967	0.234	−29.06
−0.15137	1986	0.236	−22.25
−0.02686	2037	0.238	−3.95
0.36133	2196	0.240	53.10
0.80078	2376	0.242	117.69
0.58594	2288	0.244	86.11
0.35156	2192	0.246	51.67
0.25147	2151	0.248	36.96
0.17578	2120	0.250	25.83
0.06348	2074	0.252	9.33

-0.12207	1998	0.254	-17.94
-0.16846	1979	0.256	-24.76
-0.17578	1976	0.258	-25.83
-0.17334	1977	0.260	-25.48
-0.16602	1980	0.262	-24.40
-0.18311	1973	0.264	-26.91
-0.19287	1969	0.266	-28.35
-0.20264	1965	0.268	-29.78
-0.21484	1960	0.270	-31.57
-0.21729	1959	0.272	-31.93
-0.21240	1961	0.274	-31.22
-0.20020	1966	0.276	-29.42
-0.18311	1973	0.278	-26.91
-0.12207	1998	0.280	-17.94
0.07080	2077	0.282	10.41
0.53223	2266	0.284	78.22
0.69092	2331	0.286	101.54
0.49072	2249	0.288	72.12
0.40039	2212	0.290	58.84
0.27344	2160	0.292	40.19
0.16602	2116	0.294	24.40
0.00244	2049	0.296	0.36
-0.14893	1987	0.298	-21.89
-0.17334	1977	0.300	-25.48
-0.17578	1976	0.302	-25.83
-0.17578	1976	0.304	-25.83
-0.16846	1979	0.306	-24.76
-0.18066	1974	0.308	-26.55
-0.20508	1964	0.310	-30.14
-0.21729	1959	0.312	-31.93
-0.21729	1959	0.314	-31.93
-0.21240	1961	0.316	-31.22
-0.20752	1963	0.318	-30.50
-0.18555	1972	0.320	-27.27
-0.15381	1985	0.322	-22.60
-0.06836	2020	0.324	-10.05
0.20020	2130	0.326	29.42
0.74951	2355	0.328	110.15
0.86182	2401	0.330	126.66
0.57373	2283	0.332	84.32
0.35400	2193	0.334	52.03
0.21240	2135	0.336	31.22
0.10742	2092	0.338	15.79
-0.07568	2017	0.340	-11.12
-0.14893	1987	0.342	-21.89
-0.15381	1985	0.344	-22.60
-0.15137	1986	0.346	-22.25

-0.14160	1990	0.348	-20.81
-0.13916	1991	0.350	-20.45
-0.16846	1979	0.352	-24.76
-0.19287	1969	0.354	-28.35
-0.20264	1965	0.356	-29.78
-0.20264	1965	0.358	-29.78
-0.20020	1966	0.360	-29.42
-0.19043	1970	0.362	-27.99
-0.17334	1977	0.364	-25.48
-0.12207	1998	0.366	-17.94
0.05859	2072	0.368	8.61
0.55664	2276	0.370	81.81
0.63477	2308	0.372	93.29
0.25147	2151	0.374	36.96
0.10986	2093	0.376	16.15
0.09033	2085	0.378	13.28
0.11719	2096	0.380	17.22
-0.01709	2041	0.382	-2.51
-0.15137	1986	0.384	-22.25
-0.17822	1975	0.386	-26.19
-0.18555	1972	0.388	-27.27
-0.18555	1972	0.390	-27.27
-0.17822	1975	0.392	-26.19
-0.20020	1966	0.394	-29.42
-0.22217	1957	0.396	-32.65
-0.23438	1952	0.398	-34.45
-0.23682	1951	0.400	-34.80
-0.23193	1953	0.402	-34.09
-0.22461	1956	0.404	-33.01
-0.21973	1958	0.406	-32.29
-0.18311	1973	0.408	-26.91
-0.10010	2007	0.410	-14.71
0.15869	2113	0.412	23.32
0.70313	2336	0.414	103.34
0.74707	2354	0.416	109.79
0.58350	2287	0.418	85.75
0.39307	2209	0.420	57.77
0.20508	2132	0.422	30.14
0.08789	2084	0.424	12.92
-0.09766	2008	0.426	-14.35
-0.18799	1971	0.428	-27.63
-0.19531	1968	0.430	-28.70
-0.20508	1964	0.432	-30.14
-0.19775	1967	0.434	-29.06
0.04395	2066	0.436	6.46
-0.21973	1958	0.438	-32.29
-0.23682	1951	0.440	-34.80

-0.25147	1945	0.442	-36.96
-0.25391	1944	0.444	-37.32
-0.23926	1950	0.446	-35.16
-0.23193	1953	0.448	-34.09
-0.21729	1959	0.450	-31.93
-0.16602	1980	0.452	-24.40
-0.02441	2038	0.454	-3.59
0.41260	2217	0.456	60.64
0.68359	2328	0.458	100.47
0.32471	2181	0.460	47.72
0.13184	2102	0.462	19.38
0.10254	2090	0.464	15.07
0.12940	2101	0.466	19.02
0.03174	2061	0.468	4.66
-0.13672	1992	0.470	-20.09
-0.17090	1978	0.472	-25.12
-0.17578	1976	0.474	-25.83
-0.17822	1975	0.476	-26.19
-0.16602	1980	0.478	-24.40
-0.13916	1991	0.480	-20.45
-0.17822	1975	0.482	-26.19
-0.20264	1965	0.484	-29.78
-0.20752	1963	0.486	-30.50
-0.20752	1963	0.488	-30.50
-0.19775	1967	0.490	-29.06
-0.18799	1971	0.492	-27.63
-0.15625	1984	0.494	-22.96
-0.09521	2009	0.496	-13.99
0.09033	2085	0.498	13.28
0.59082	2290	0.500	86.83


Pressure vs. Time
Test Case: April 16, 1993
140
120
100
80
60
40
20
0
-20
-40
Pressure, P (psig)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Time, t (sec)
CH4+CO2+O2

APPENDIX Q

CALIBRATION OF PRESSURE TRANSDUCER

Two options for calibrating the pressure transducer exist:

A. Calibration by means of a dead weight tester (not discussed)*

B. Manipulation of charge amplifier

MANIPULATION OF CHARGE AMPLIFIER:

This method is possible if the highest pressure expected during measurement, p_{max}, is known. To maintain a specific output voltage for a specific input pressure, an "incorrect" transducer sensitivity value can be set at the push button potentiometer. This value is derived from the following equation:

$$S = \frac{TRANS.\ SENS.\ x\ p_{\max}\ measurement\ x\ V_{out}\ \max(V)}{RANGE\ x\ V_{out}\ (V)}$$

where: (S) is the value in pC/bar to be set at the potentiometer.
V_{out} max always = 10V.
TRANS. SENS. is in (pC/bar)
p_{max} measurement is in (bar)
RANGE is in (bar)

EXAMPLE: TRANS. SENS. : 2.23 pC/bar
p_{max}: 600 bar
V_{out}: 10 V

RANGE = 1 k. Derived from the position of the decimal point for the transducer sensitivity and p_{max} measurement

$$S = \frac{2.230\ x\ 600\ x\ 10}{1000\ x\ 10} = 1.338$$

Setting the "incorrect" TRANS. SENS. at 1.338 pC/bar will give an output voltage of 10 V at a pressure of 600 bar

* This method is more accurate

APPENDIX R

BUDGET

NO.	DESCRIPTION	COST	TAX
1	MOUNTING HARDWARE	$8.46	$0.38
1	DUMMY BOLT	$0.85	$0.04
1	SOCKET	$2.49	$0.15
2	CABLE CLAMPS	$1.99	$0.09
1	SHOP MANUAL	$25.30	$1.14
1	HEAD GASKET	$6.60	$0.30
1	PHOTOGRAPHS AND FILM	$40.00	$1.80
1	SLIDE DEVELOPING	$5.00	$.23
1	LINE RECEIVER	$1.29	$.06
	SUBTOTAL: TOTAL:	$91.98 $96.17	$4.19

FINAL REPORT
FOR THE
MARS OXYGEN PROCESSOR
NEW FURNACE PROJECT

Technical Advisors

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Group Members

Keith Davis

Wes Wigginton

Mike Uenking

MEM 434

April 21, 1993

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ABSTRACT

Several studies are underway to convert carbon dioxide into usable oxygen to help support future Mars missions. Since the Mars atmosphere is comprised of 95.32% CO_2, these studies are necessary to determine whether the utilization of this abundant atmospheric component can keep launch and payload costs down. A cooperative study between the University of Arizona and Old Dominion University is currently utilizing a zirconia cell as the oxygen processing element. 8% yttria-stabilized zirconia has excellent high temperature characteristics and allows oxygen ions to be transported ionically through the membrane when an electric potential is maintained across the thin zirconia disk at the prescribed temperature. The University of Arizona project team has successfully produced a repeatable oxygen flowrate from the cell when operated at Earth atmospheric conditions; therefore, the Old Dominion University project team was assigned the task of designing a vacuum test chamber that can generate the ambient pressure conditions that exist in the Mars atmosphere. This chamber will be heated in an ordinary tube furnace to meet the temperature criteria set forth by the University of Arizona. The current chamber design consists of an alumina shell with a stainless steel cap so that standard stainless steel tube fittings can be used on the exterior. These fittings will provide the transition from the interior alumina tubes to standard steel tubes that will connect to the gas storage tanks and the pump mechanism. Two of the tubes will allow instrumentation such as thermocouples to be inserted into the vacuum chamber. One tube will be used to allow CO_2 to be pumped in while another tube will export any waste gas. Finally, a center tube will be used to pump out the usable oxygen from the zirconia cell. Once this

chamber design is complete and is manufactured, future project teams will test the zirconia cell in the chamber to see if similar results to those from the University of Arizona can be produced.

1. INTRODUCTION

Over the past thirty years, research has been done in determining what was necessary to successfully land, explore, and return from the planet Mars. Thirty years ago, launch vehicles were too large to be able to land on the planet and ~~to be able to~~ return. Another problem that was faced was that the Earth–produced supply of oxygen for life support and as an oxidizer for rocket propellant could be depleted in such a way that a return to Earth would be impossible and the ability to sustain manned exploration would be futile. Since the major constituents of the Mars atmosphere consist of CO_2 and N_2, this feedstock is prevalent. To have sufficient oxygen for a complete round trip mission would create an enormous cost index on the design of the launch vehicle. Therefore, current research is being done to extract usable oxygen from Mars atmospheric carbon dioxide using a solid electrolyte process in which 8% yttria-stabilized zirconia is this solid electrolyte. That approach has the potential to help substantially reduce round trip cost for Mars missions.

Ever since the idea to explore the moon existed, other planets in our solar system have brought much interest to many researchers. In the 1960's, the United States of America was able to successfully explore and land on the moon. But also during this time, research was being done to find out information on our two nearest planets, Venus and Mars. "Mission to Mars," the terminology used by current researchers and politicians, is an effort to successfully explore and land on the planet Mars. But as mentioned previously, this "Mission" was initiated during the 1960's through the use of several exploration probes known as Mariner and Viking. Mariner first was sent out to determine information about Venus, but then later missions were designed to retrieve data on Mars. The next effort was to send out a probe that would land on Mars and send data, not only on the atmospheric composition, but also on the soil and terrain composition. This probe was known as Viking. For the first time, researchers were able to get an accurate estimate of the Mars atmosphere composition.

2. MOTIVATION

Studies are underway to determine what is needed to sustain a successful mission to the planet Mars. As mentioned previously, one of the problems that is faced is the high cost incurred due to the amount of propellant and life support consumables that would be needed to sustain such a mission to Mars. Sridhar and Iyer [Ref. 1] report that more than 80% of a spacecraft's mass is due to the propellant; therefore, if a propellant production system could be installed on the planet's surface, the Earth launch mass requirement would decrease substantially and cost, in turn, is greatly reduced. One way to solve this problem is through the use of an in-situ oxygen production system that enables Martian systems to produce oxygen from carbon dioxide. Since carbon dioxide comprises about 95.32% of the Mars atmosphere as discovered in the data sent by the Viking probe, extraction of oxygen from carbon dioxide is very attractive. A demonstration model has been constructed and tested previously. Past research teams at Old Dominion University were presented with the task of simulating the Mars atmospheric conditions by developing a furnace/vacuum chamber, while a team at the University of Arizona developed a sample zirconia cell and tested it to try and produce a noticeable flowrate of oxygen. But, the existing furnace/vacuum chamber unit at Old Dominion University had poor temperature profile characteristics and vacuum leaks. Therefore, this current research at Old Dominion University has been working on correcting these problems by designing a new furnace and vacuum chamber combination that will permit the simulated Mars oxygen production at sub-atmospheric pressures.

3. ZIRCONIA CELL

This ongoing cooperative study being done with Vaniman et al. [Ref. 2], the research team at the University of Arizona, and Old Dominion University is attempting to investigate the operation of a zirconia test cell that can demonstrate the in-situ production of oxygen from low-pressure carbon dioxide. Mr. Vaniman has performed several tests on a zirconia test specimen at an elevated temperature (approx. $1000^{\circ}C$) and at atmospheric pressure and has produced data [Ref. 2]. To further emulate the true operating conditions on the Mars surface, it is necessary to reduce the cell pressure to around 0.1 atm. Therefore, a vacuum chamber was required which could accommodate the existing zirconia cell design and satisfy the operating condition requirement.

As mentioned previously, the cell is comprised of yttria-stabilized zirconia (ZrO_2-Y_2O_3 8% mole). As shown in Figure 1, the cell consists of a 1.150" dia. x 1.575" long x 1/8" thick cylindrical zirconia crucible (Coors Ceramics, Ceramicon Designs Ltd., CO) and a 1.150" dia. x .025" thick zirconia disk that is connected to the crucible via a ceramic paste which is then fired (in order to set the paste). Platinum electrodes are pasted to the disk, in the same manner, to provide a means to maintain an electric potential across the disk. 1/8" dia.

alumina tube is pasted to the crucible to provide an exit port for the removal of oxygen inside the crucible.

This zirconia cell is used as a simple ionic transport vehicle and at elevated temperatures an induced current provides a means for oxygen ions to migrate through the crystal lattice and be recombined subsequently to form oxygen molecules. This process is described in the following section.

3.1 ELECTROLYTE PROCESS

The carbon dioxide, when heated to the prescribed temperatures after coming in contact with the induced current through the zirconia disk, is dissociated into CO and O^{++} ions. Because of the properties of yttria-stabilized zirconia at this elevated temperature, application of a voltage across the crystal lattice of the zirconia allows these oxygen ions to be conducted ionically through the material. After passing through the matrix, these ions combine to form O_2 releasing two electrons which are removed by the interior electrode and returned to the power supply. The resulting oxygen is then removed via the alumina tube. Careful attention must be taken to stay below the critical cell voltage so that the zirconia disk is not destroyed. Previous tests have shown that the zirconium oxide does contribute some oxygen molecules from its own lattice during this process, but the amounts are so small that it is negligible.

4. FURNACE SPECIFICATIONS

In order for the Mars Oxygen Processor System to operate, the carbon dioxide (CO_2) must be elevated to the temperature range of approximately

950°C to 1000°C and maintained for the dissociation of the CO_2 to occur. The use of a vacuum chamber to simulate the Mars atmospheric pressure requires that a heat source be selected that is capable of maintaining the chamber at these temperatures while the process occurs. Thus the thermal heat capacity and temperature gradient profile for the unit must also be measured in order to position the vacuum chamber in the unit effectively. To accomplish this task, the selection of a commercial furnace led the team to consider several design options.

The initial search for a furnace was to purchase a new open ended Tube Furnace for this purpose. Figure 2 shows the basic design for a furnace of this type. The selection of this particular type was driven by the initial proposed design of the Zirconia canister as obtained from the University of Arizona, Figure 3, shows the initial design. However, a revised design for the Zirconia canister made this selection unnecessary.

The furnace now could be based upon a more conventional design for a furnace with a single entry port. This would greatly reduce the heat loss from an open ended furnace.

This change allowed the team to select an existing furnace unit that was already available from the Material Science Lab at O.D.U. The furnaces available were manufactured by Lindberg Corporation, with model designation , Hevi-duty Furnace Type # 59334. Figure 4 shows the basic dimensions of the furnace. In addition, another identical unit was on hand, thus a spare is available for use, should the first unit fail to operate properly. They have a maximum temperature capability listed as 1250°C. They incorporate a cylindrical shaped heat chamber with a 5 inch diameter opening, which has and a depth of 10 inches. The internal heating coil only extends approximately 8 inches from the bottom of the heated chamber. Figure 5 shows this configuration.

In order to position the vacuum chamber inside the furnace efficiently, a thermal profile must be obtained for the cavity. Two individual tests will be performed to obtain the necessary information. The following text outlines the required test program, results, problems, and conclusions for each test.

4.1 TEST # 1 : STATIC TEMPERATURE PROFILE TEST

PURPOSE : To map the internal thermal gradient profile of the furnace cavity. This test considered the static temperature distribution, because, during O_2 production, no structure will be placed inside the unit to cause significant heat transfer out of the furnace. This particular test has documented the location of the highest wall temperature zone within the unit. With this information, the zirconia canister or a mock up can be positioned at the location of maximum heat transfer from the furnace.

TEST PROCEDURE : The interior of the furnace was instrumented with thermocouples positioned at equal distances from the bottom of the unit and set near the wall. The furnace will be operated at several temperature ranges to obtain the steady-state temperature profile of the unit. Figure 6 shows the basic pattern needed for the test. A temperature measuring system was used to record the output from the furnace. This system consisted of a Fluke Digital Thermometer, Model 2109A, a Fluke Thermocouple Scanner, Model 2300A, and finally, a Fluke programmable printed, Model 2030A. The unit was set to record in degrees centigrade with a time interval of 60 seconds between data sets.

4.2 Test Results : Static Temperature Profile

The time required for the Lindberg Furnace to reach the required temperature of 950°C was approximately 2 hours. This temperature was recorded at the designated, # 2 thermocouple which was located at a height of 2 inches above the bottom of the unit. At that time, the furnace temperature was allowed to rise so that the temperature profile could be recorded when each thermocouple registered 950°C . Figures 7A through 7E show the temperature patterns recorded when each individual thermocouple registered 950°C, during increasing time. Figure 7F graphs all the temperature profiles for the furnace. The temperature rise profile for the furnace's centerline is shown in Figure 8. The center plane of the furnace's heating element was located at a height of 4 inches from the bottom of the unit. The profile shows an smooth temperature rise for the furnace vs. the time required to reach the operational temperature of 950°C. Once the a temperature of 950°C was reached on thermocouple # 6, the temperature setting on the furnace's automatic controller was lowered until it started cycling about the 950°C temperature. Once the controller was engaged, no attempt was made to maintain the 950°C temperature at any particular location. The unit was allowed to reach an equilibrium level so measurements as to the ability to maintain a constant temperature could be recorded. Figure 14, shows the temperature cycling profiles which were equal to or above the 950°C range.

ORIGINAL PAGE IS
OF POOR QUALITY

4.3 Problems

The furnace temperature sensor was found not to be very accurate when compared to the internal thermocouples. While the thermocouples recorded a temperature in excess of 950°C , the furnace's unit read only 750°C. This discrepancy could be due in part to the location of the sensor within the furnace itself. However, no attempt was made to disassemble the unit an locate the sensor position. Therefore, it will be necessary for sensor units to be recalibrated for future operation. Also, the temperature controller used in the furnace is a simple on-off control type and it simply cycles power on and off the heating elements. The installation of a more modern microprocessor-based controlled sensor will allow for greater control and accuracy within the unit.

4.4 TEST # 2 : THERMAL HEAT LOAD TEST

PURPOSE: To obtain a realistic thermal heat transfer loss on the furnace. It will provide information on the heat capacity of the furnace along with temperature ranges on the inlet and outlet lines of the vacuum chamber.

TEST PROCEDURES : In this second test, a dummy vacuum chamber will be placed inside the furnace cavity. It will again be instrumented with thermocouples to measure the temperatures inside the unit, along with the temperatures along a simulated inlet tube (through the vacuum chamber). Figure 10 is a schematic of the test components.

4.5 Test Conclusions:

The Lindberg Furnace meets the performance requirements needed for the operation in the Mars oxygen processor simulation. Given its design and type of controller, it will be a simple unit to operate and give good service. However, the installation of a new controller will be required if finer control is needed, especially if stepped temperature inputs are required. Also, the Thermal Heat Load Test should be conducted to further measure the capacity of the furnace and document a baseline for future operations of the unit. The second test which was to be performed on the furnace could not be completed due to the unavailability at the time of external canister. The general outline for this test is provided for future reference.

5. THE VACUUM CHAMBER

As stated earlier, the operating conditions for the system are a pressure of approximately 0.1 atm and a temperature between 600°C and 1000°C. The primary purpose of the vacuum chamber is to maintain vacuum integrity and to allow heat transfer from the tube furnace to the simulated carbon dioxide atmosphere inside the chamber. Several designs have been considered for the chamber. The initial design is shown in Figure 11. It was a very simple hollow cylinder with the zirconia cell located in the center of the cylinder. Concerns about the structural integrity of the zirconia cell supports and possible heat transfer problems required that this design be modified. Figure 12 shows the modified chamber design. Some of the features of this design are the addition of radiation baffles, extension of the tubes further from the top of the chamber, and the use of very simple shapes for the individual parts. The radiation baffles were added to reduce the radiation heat transfer in the direction of the cap and to make the assembly stronger. The tubes were extended to provide better cooling and the shapes of the individual parts were kept simple because of construction difficulties related to complex geometry and cost.

The final design was prompted by the favorable thermal analysis results and the discovery of a vendor that stocked many of the parts required to construct the chamber. The results of the simplified thermal analyses revealed that the length of tube extending from the chamber can be eliminated and the cap of the chamber will be much cooler than expected. Several of the parts that were required to construct the chamber were eliminated because a single assembly was found that replaces all of the parts. The final chamber geometry and its position with respect to the tube furnace are shown in Figure 13 and 14 respectively.

The chamber consists of two major assemblies. The external assembly is a canister that maintains vacuum integrity. This assembly can be reused for different geometry zirconia cells without modification. The internal assembly is a series of tubes and plates. The purpose of the internal assembly is to provide for plumbing connections (carbon dioxide inlet, oxygen outlet, waste gas outlet), instrumentation passages (thermocouples and power leads), and a seat for the zirconia cell. The cap (flange) is part of the internal assembly and an O-ring seal maintains the vacuum integrity between the two assemblies. Since several components are joined with high temperature adhesives in the internal assembly, that equipment probably cannot be reused if the zirconia cell fails. The inability to reuse this portion of the pressure vessel requires that a great deal of care be used during handling.

The material selected for the majority of the chamber is alumina. This selection was based on its high operating temperature capabilities and to match the thermal expansion of the oxygen exit tube (from the zirconia cell). The major drawbacks of this material are its cost and machinability. The material costs are high, so the design needs to be optimized as much as possible in order to reduce waste. Alumina is permeable to gas in all conditions except the fully sintered state. In the fully sintered state, it is too hard to machine with carbide tooling. The only tooling that will cut alumina is diamond chip tooling. Only a few companies offer this type of machining service and it is very expensive. Alumina is also very brittle and easily broken. Extreme caution must be exercised when handling this material.

The cap is a 300 series stainless steel. This series of stainless steel is suitable in high temperature applications and is readily available. The transition from alumina tubes inside the chamber to stainless steel tubes outside the chamber occurs in the cap. A 1/8 diameter tapered pipe thread is provided for each tube to install a fitting suitable to attach to the steel tubing. The style of fitting to use has not been determined. The two best choices are 37° flared (AN fittings) and flareless (Swagelock). The team responsible for the integration of the furnace and operation of the entire system should choose the type of fitting at the time of integration. Results of thermal and structural analyses are given in Appendix A. Appendix C contains reduced size detailed drawings of the vacuum chamber. Full size drawings are also in the project file.

An estimate for the construction and assembly of the second chamber design was provided by Aremco Materials. The total cost was estimated at $7000 for one chamber. For the final design, Coors Ceramics Company provided the estimate for the alumina parts and Aremco Materials provided the estimate for the adhesives. The total estimated cost for two complete chambers less assembly was $2800. The purchasing or acquisition of the materials required to construct two vacuum chambers based on the final design is complete. Details such as the length of insertion of the outer assembly in the furnace and the length of the inner alumina tubes are only suggestions at this point. It may be desirable to allow the outer assembly to rest on the bottom of the furnace thereby reducing the load on the support ring. This will also require the shortening of the internal tubes. Since the internal tubes were ordered longer than required, the shortening of the internal tubes is required anyway. The material safety data sheets and curing procedures for the adhesives are provided in Appendix B. It is intended that one of the chambers be assembled without the internal assembly and used as the dummy chamber for the thermal heat load test. This will determine the optimum position of the zirconia cell in relation to the furnace and the final length of the internal tubes can be determined.

5.1 PROBLEMS

Besides the problems of location of the zirconia cell with respect to the furnace cavity and machining fully sintered alumina, other problems exist that need to be solved. Heat transfer within the chamber and through the cap can be a major problem. Several simplified analyses and some testing will be made to determine the severity of the thermal problems and the effectiveness of our design solutions. This temperature is critical because the two chamber assemblies need to be fastened together at this point. If the temperature is too high, then a stainless steel cap and viton O-ring cannot be used.

Thermal stresses are also an important consideration. Both alumina and zirconia will crack if heated or cooled too rapidly. The temperature profile of the furnace during heating and cooling will be determined and compared to the allowable temperature-time curves that will be constructed. It may be necessary to control the rate of temperature rise and cooling time manually to prevent cracking. All of the analyses and data should be factored into the final vacuum chamber design as well as the operational procedure.

Two operational problems have been identified that need to be addressed. First is the over-pressurization of the vacuum chamber during heating. The operating temperature is four times room temperature on the absolute scale. From the ideal gas law, the internal pressure will also increase to four times the atmospheric pressure if the chamber is not vented. Alumina has excellent strength characteristics in compression, but its strength characteristics in tension are poor. It is recommended that the chamber be vented during heating. The second problem is damage to the zirconia cell by unequal pressures on the input and output sides of the wafer. The maximum allowable pressure differential is set at two pounds per square inch. An allowable pressure differential of one psi is desirable. In order to protect the cell during all phases of operation, a two way pressure relief valve can be placed between the waste gas line and the oxygen exit line. Data would be lost if a pressure differential existed that caused the valve to operate, but the cell would not be damaged.

6. FUTURE WORK

Some of the work required for this project will extend past the time limit for the present design team. It is proposed that future design teams pick up the project where this design team left off and complete the unfinished work. The work that is unfinished is assembling the test vacuum chamber, conducting the thermal heat load test described in section 4.4, modifying the furnace and/or the vacuum chamber as necessary based on the results of the thermal heat load test, assembling the primary vacuum chamber, completing assembly of the test vacuum chamber for use, and integrating the furnace/vacuum chamber assembly with the Mars Oxygen Production apparatus. It should be noted that the test vacuum chamber is identical to the primary vacuum chamber except the internal assembly is not included.

7. CONCLUSION

Since the atmospheric pressure on Mars is lower than Earth's atmosphere, a vacuum chamber is used to lower the operating pressure. The heat is provided by a tube furnace. This phase of the project concentrated on the design and analysis of the vacuum chamber/tube furnace combination. A commercial tube furnace with one end closed was located within the MEM department that was suitable for the project. The performance curves for the furnace were not available, therefore it was necessary to test the furnace. Once a furnace was located, a conceptual design for the vacuum chamber was begun. Three design improvements were required as analysis results and refinements were made. There appear to be no problems with structural integrity, vacuum integrity, thermal stress, and heat transfer.

All materials and hardware have been purchased or acquired to construct the vacuum chamber. There was not enough time to assemble and test the chamber. The members of this design team are available to advise or assist future teams with the construction and testing of the chamber.

REFERENCES

1 Iyer, Venkatesh A. and Sridhar, K. R., "Thermal Analysis, Optimization and Design of a Martian Oxygen Production Plant," NASA Space Engineering Research Center for Utilization of Local Planetary Resources, Annual Progress Report, 1990-1991.

2 Vaniman, B., et al., "Oxygen Production on Mars and the Moon," Annual SERC Report, 1991-1992.

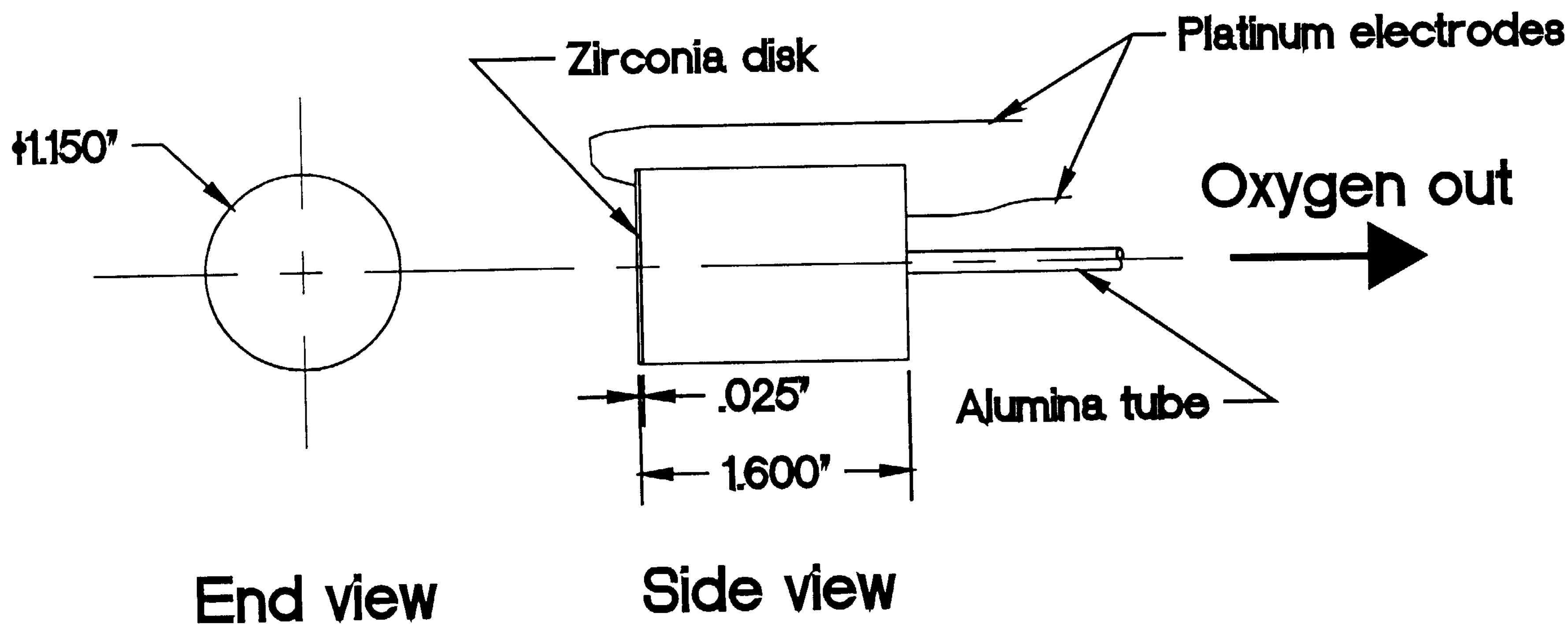


Figure 1: Schematic view of Zirconia cell

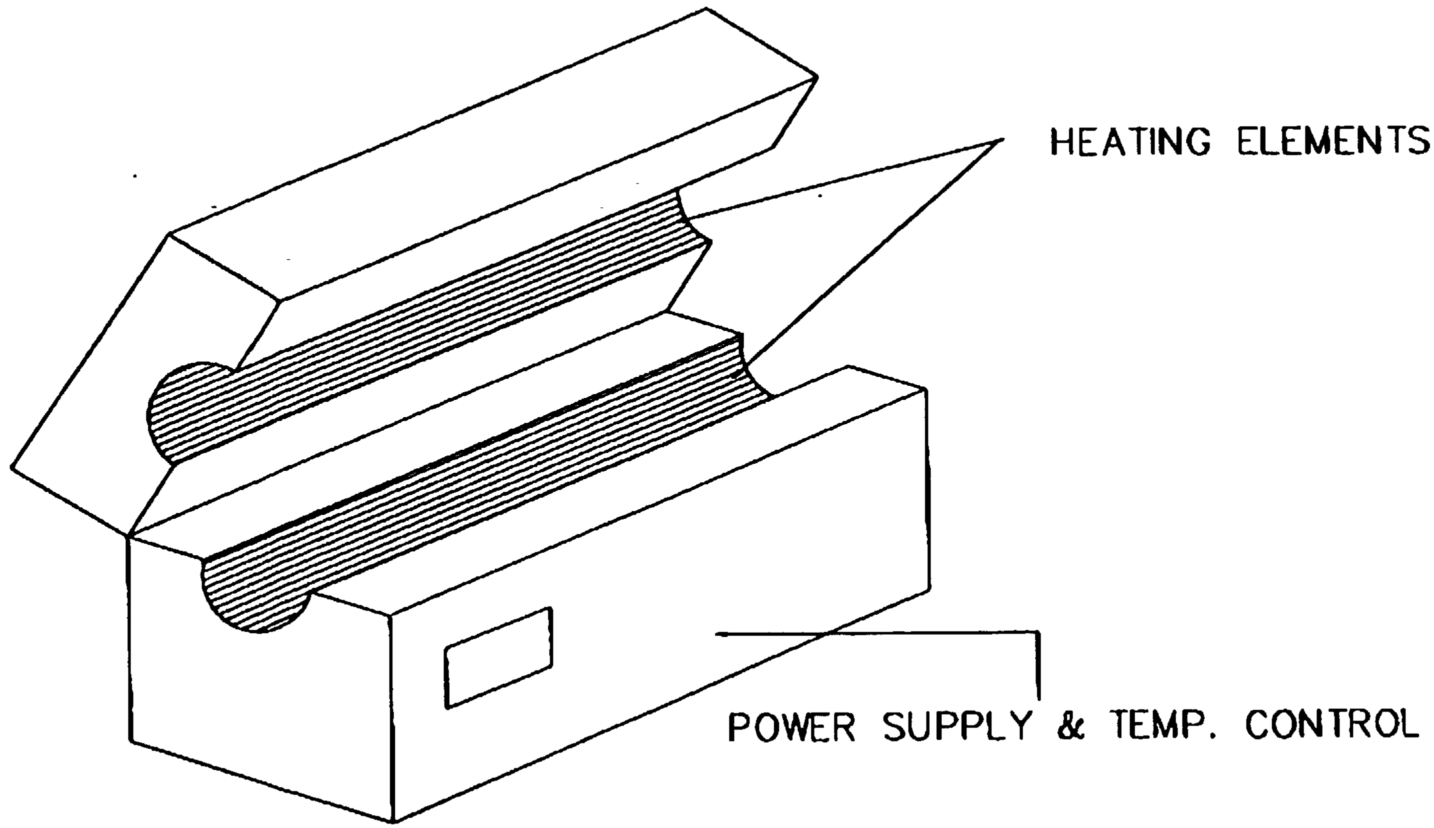


FIGURE 2 : CONVENTIONAL OPEN ENDED TUBE FURNACE DESIGN

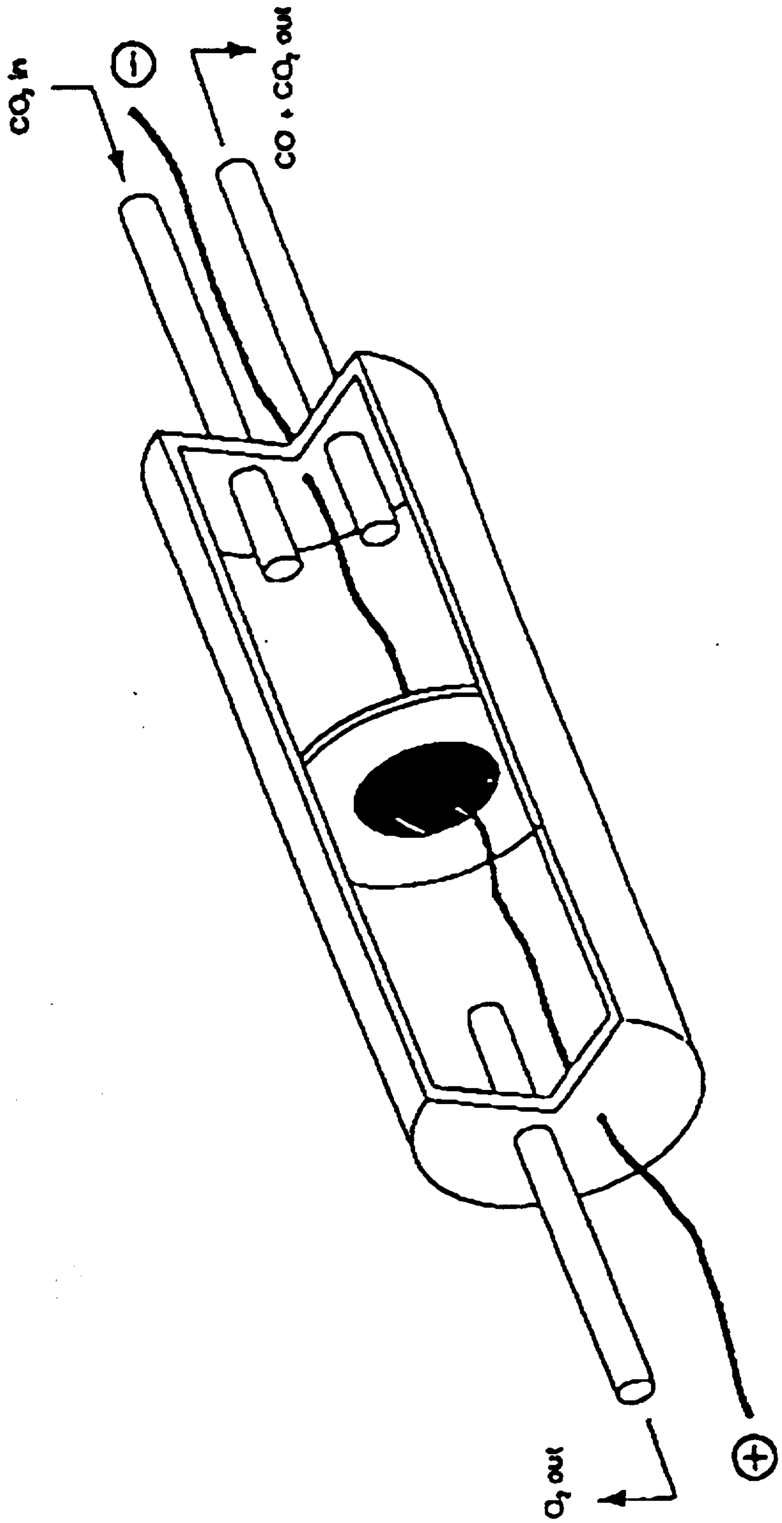


FIGURE: 3 CUTAWAY OF ZrO_2 CELL

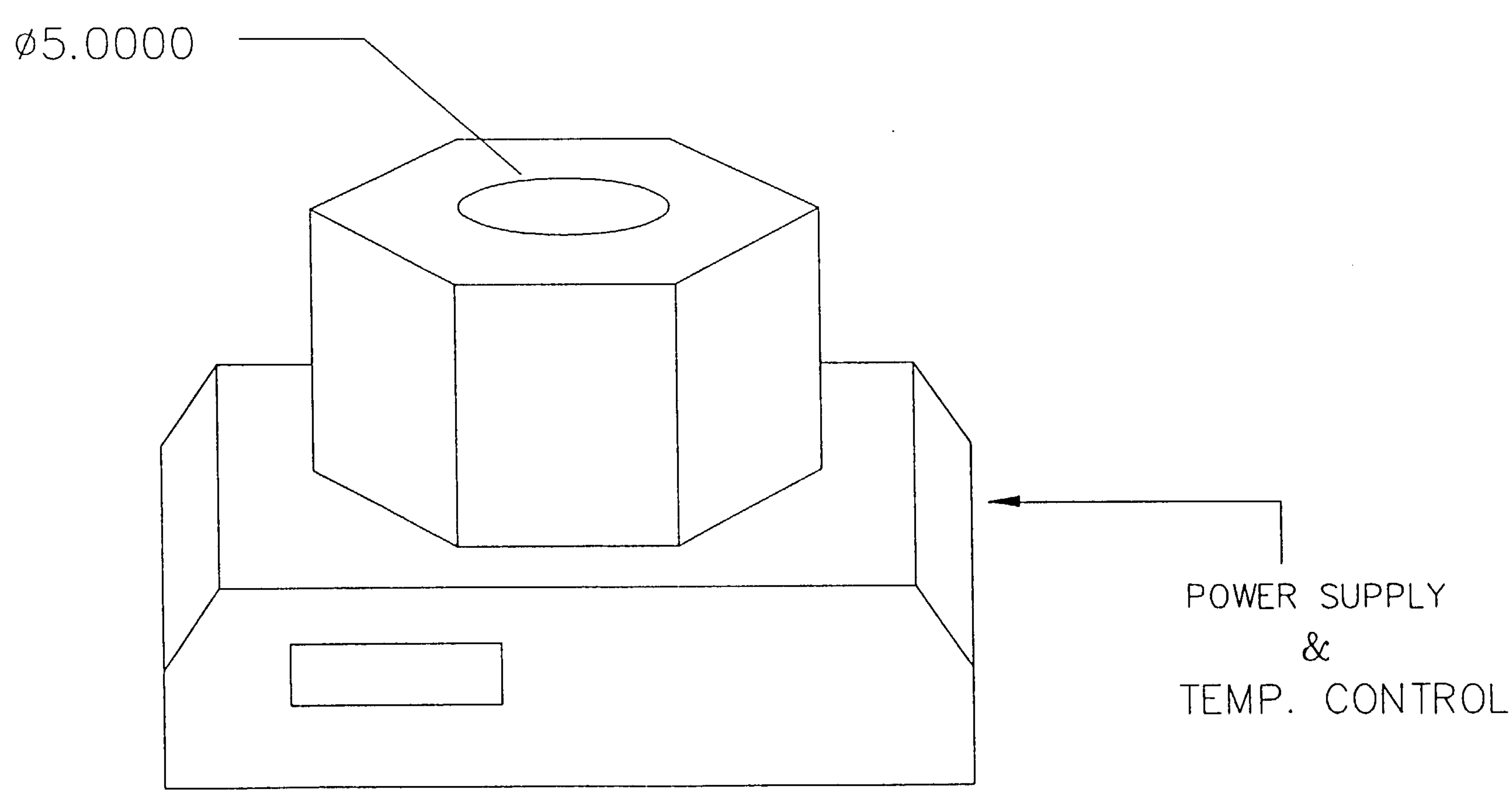


FIGURE 4 : OVERALL SKETCH OF TUBE FURNACE LAYOUT

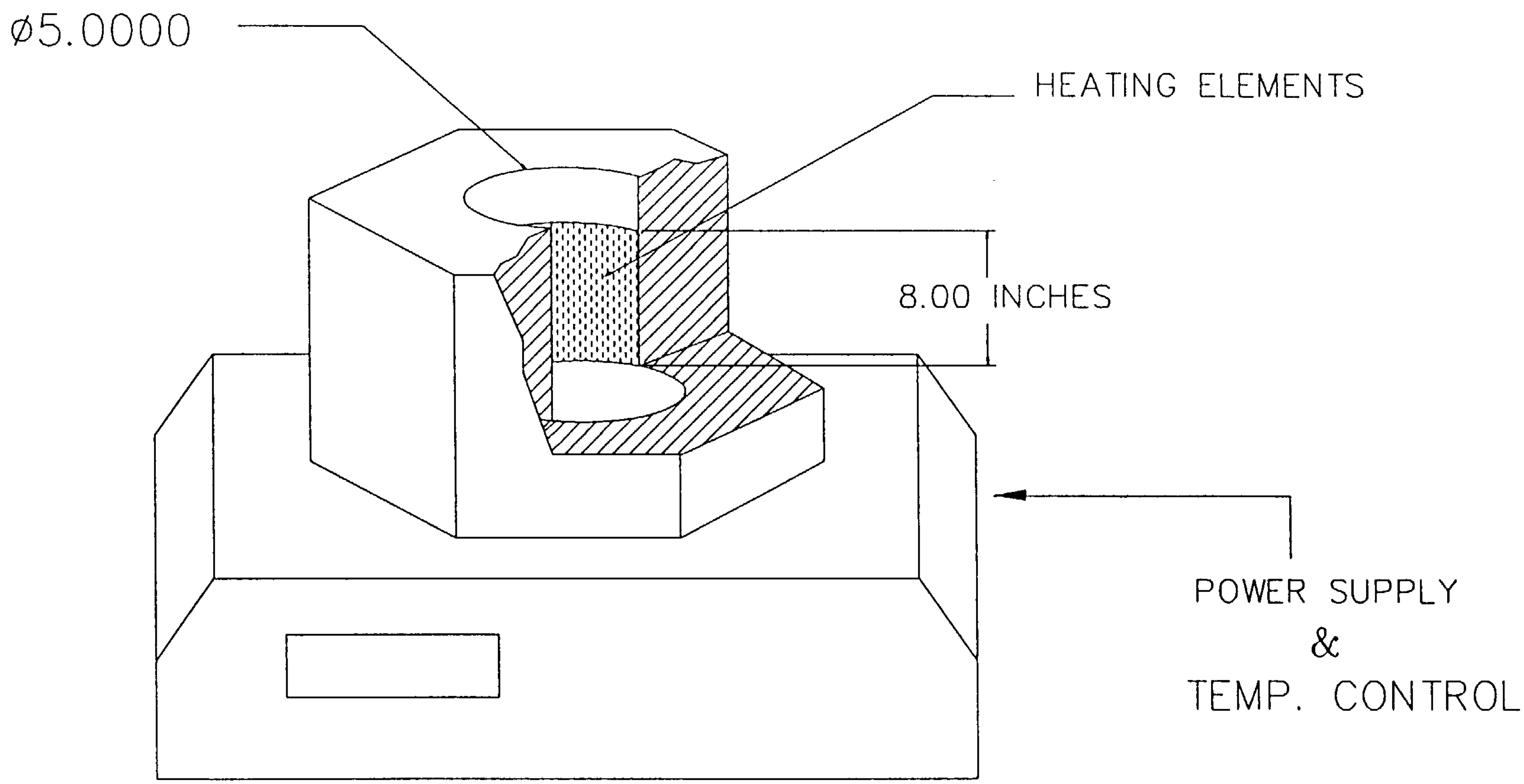


FIGURE 5 : CUTAWAY VIEW OF TUBE FURNACE HEATING VOLUME

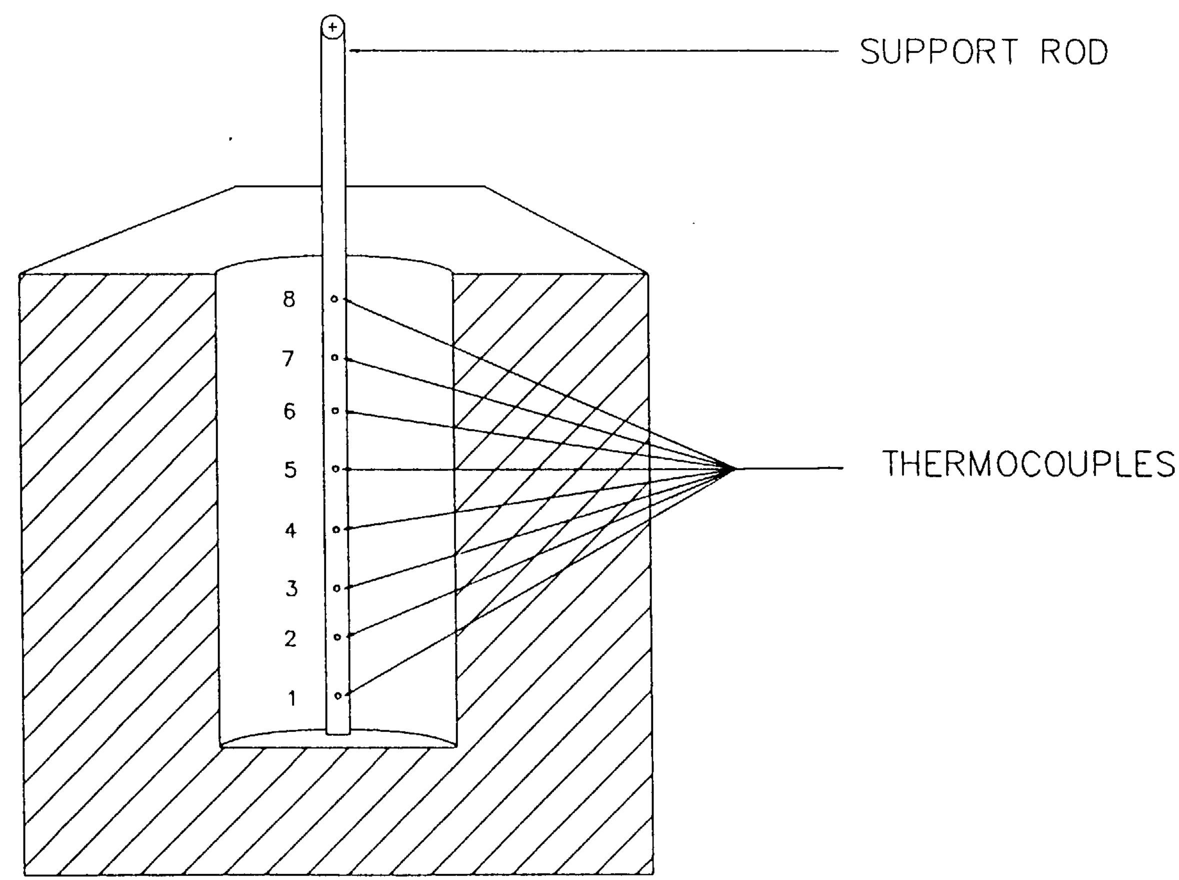


FIGURE 6 : REPRESENTATION OF STATIC TEMPERATURE PROFILE LOCATIONS

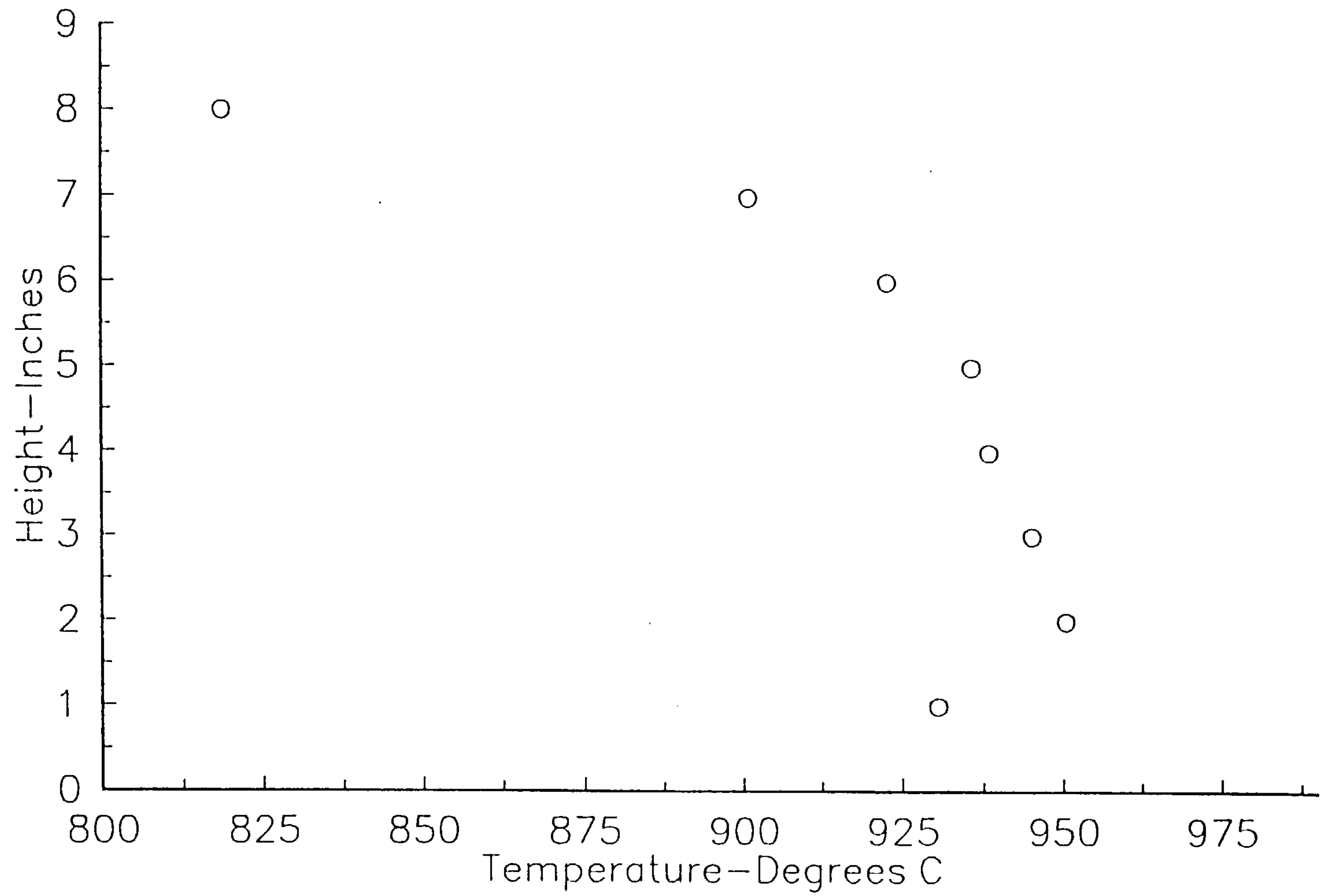


FIGURE: 7a VERTICAL TEMPERATURE PROFILE AFTER 2 HRS OF OPERATION ($t=t_o$)

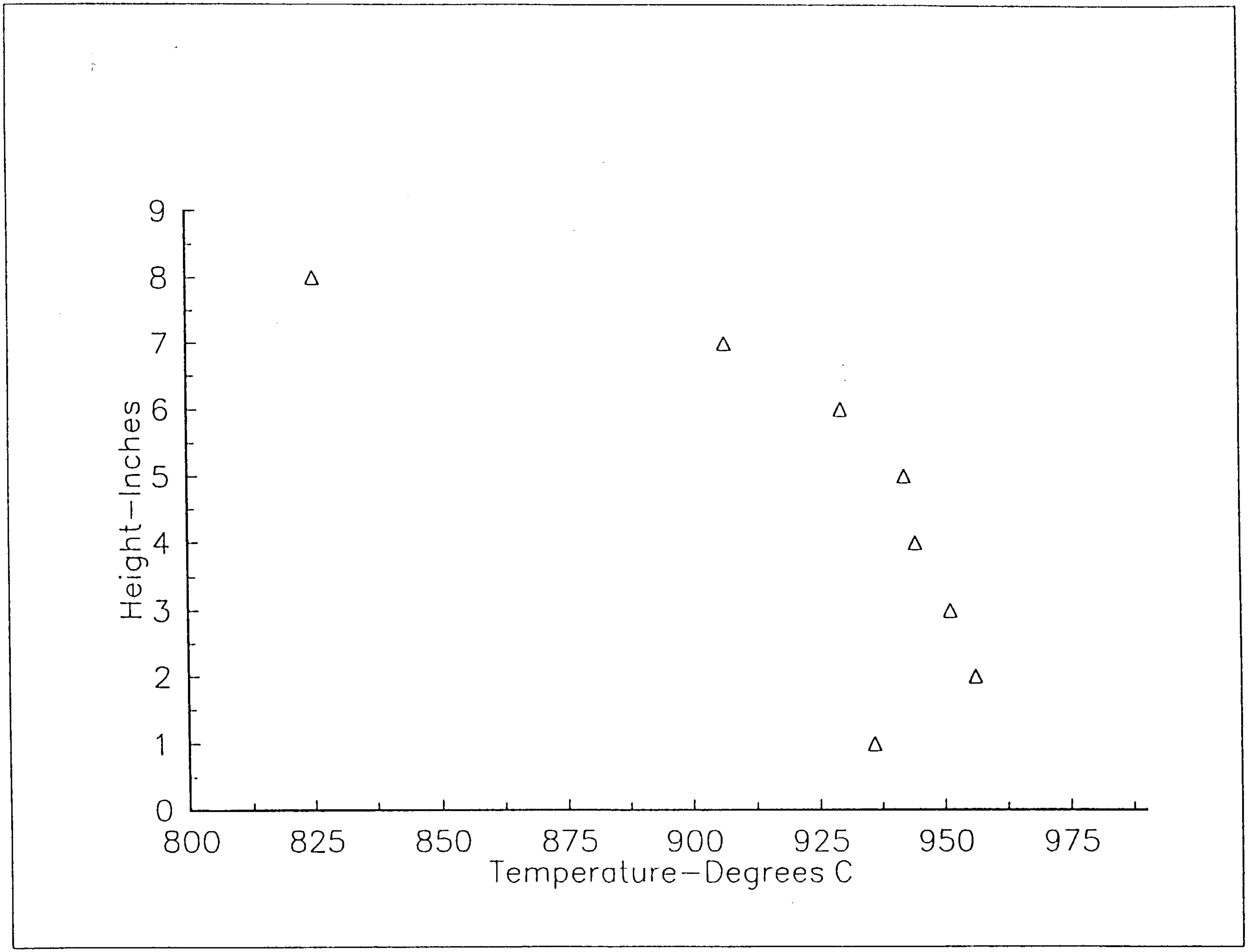


FIGURE: 7 b VERTICAL TEMPERATURE PROFILE ($t=t_o + 4$ min)

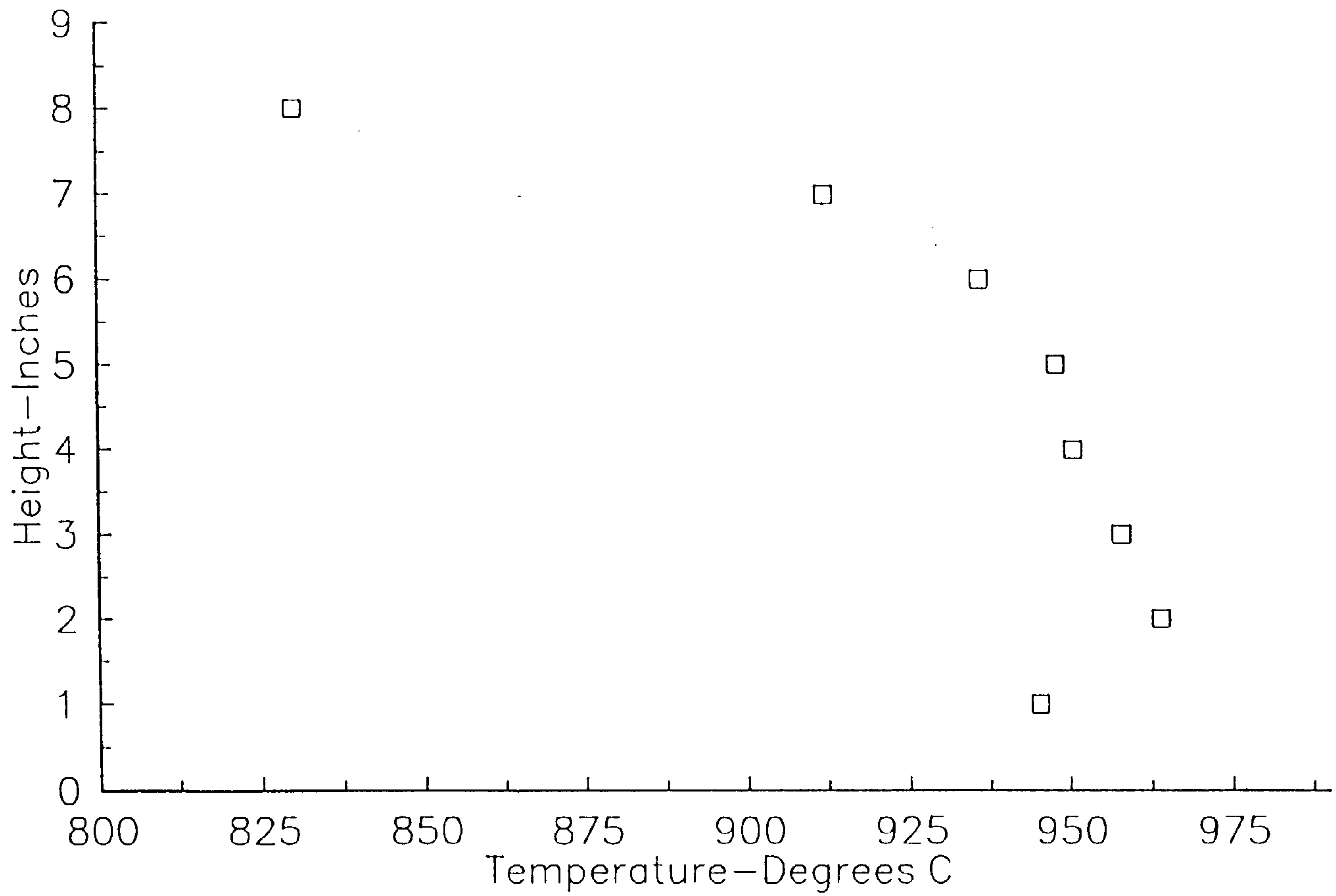


FIGURE: 7 c VERTICAL TEMPERATURE PROFILE ($t=t_o + 8$ min)

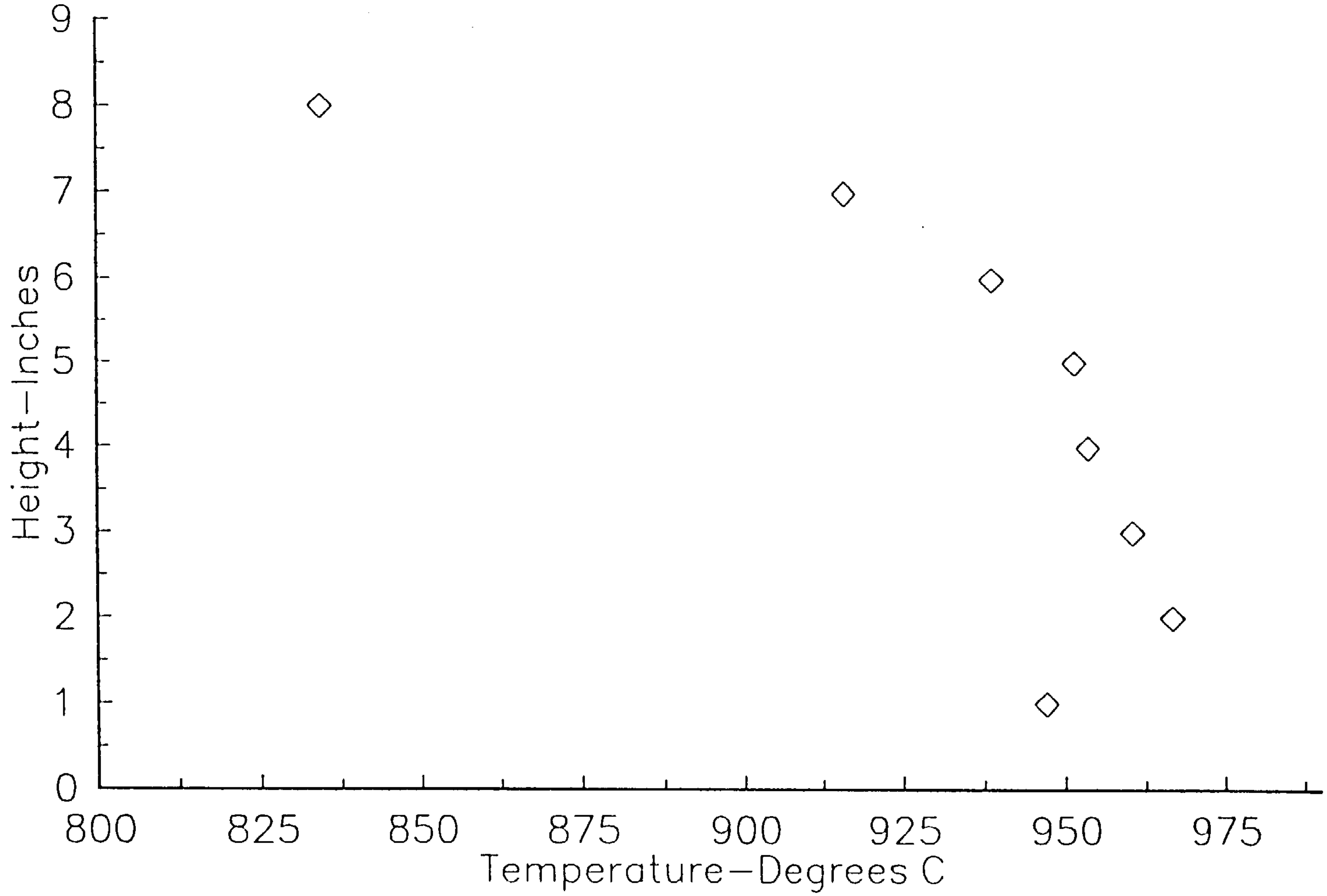


FIGURE: 7d VERTICAL TEMPERATURE PROFILE ($t=t_o$ + 10 min)

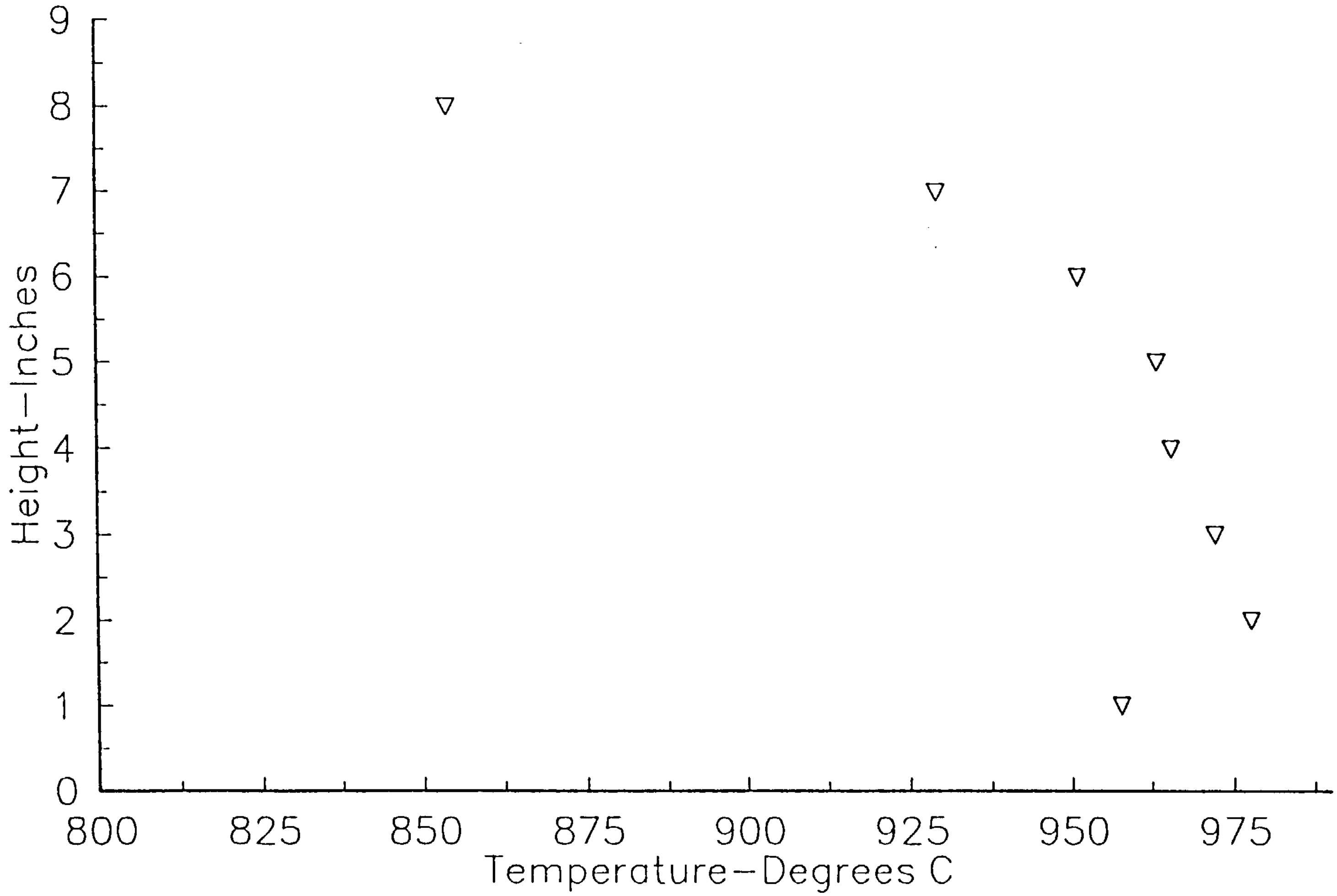


FIGURE: 7 e VERTICAL TEMPERATURE PROFILE ($t=t_o + 27$ min)

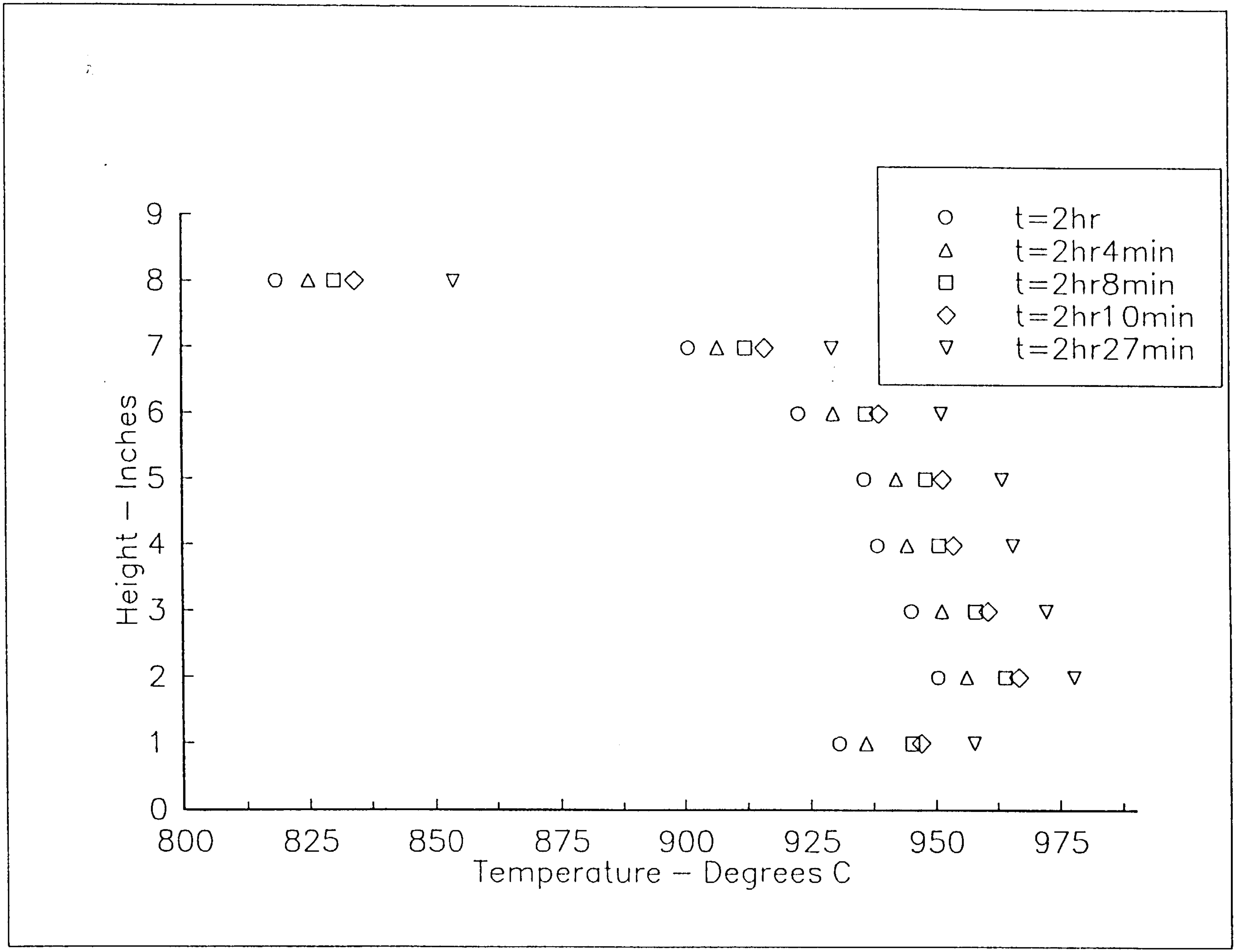


FIGURE: 7f TEMPERATURE PROFILE ON FURNACE

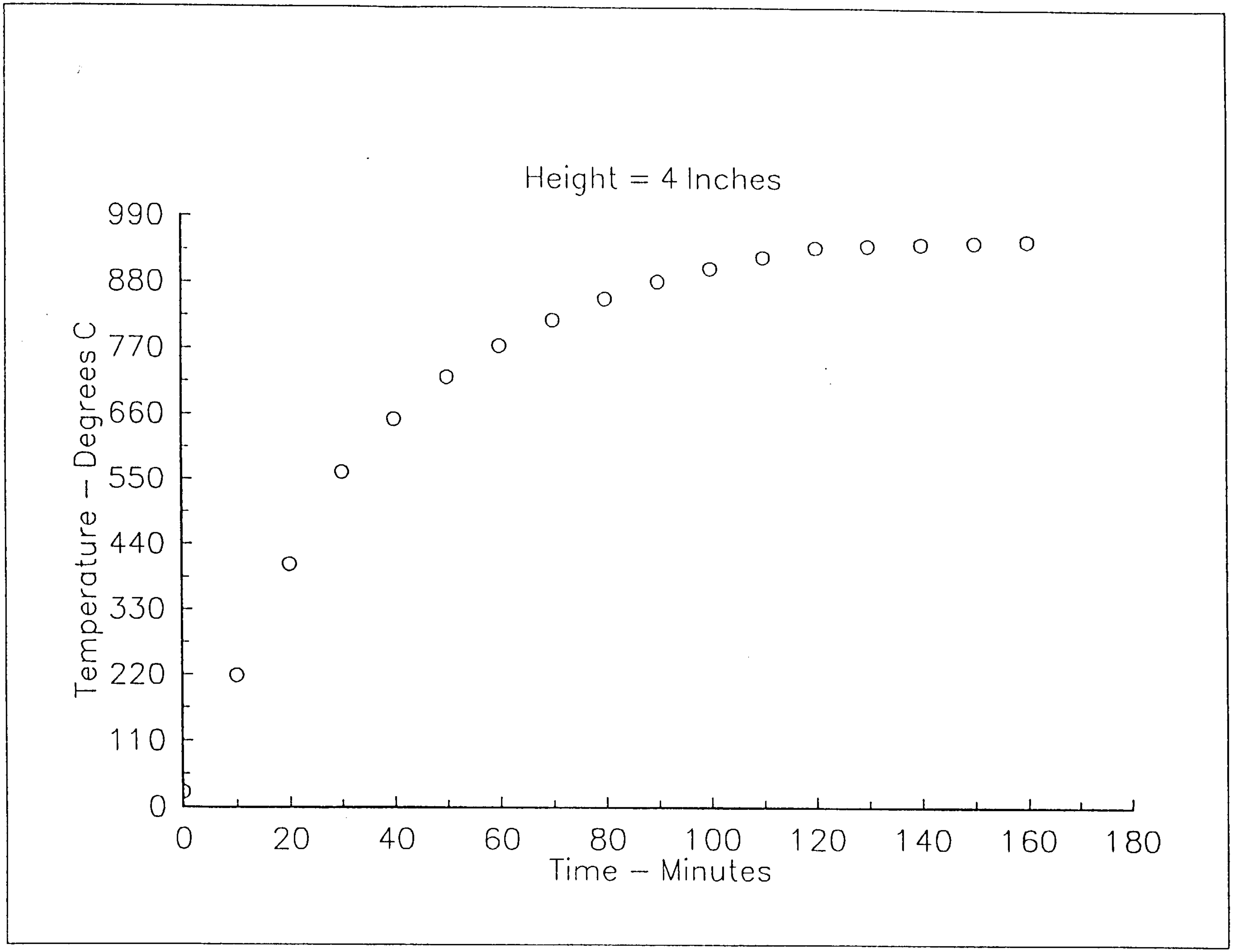


FIGURE: 8 TEMPERATURE RISE PROFILE ON FURNACE CENTERLINE

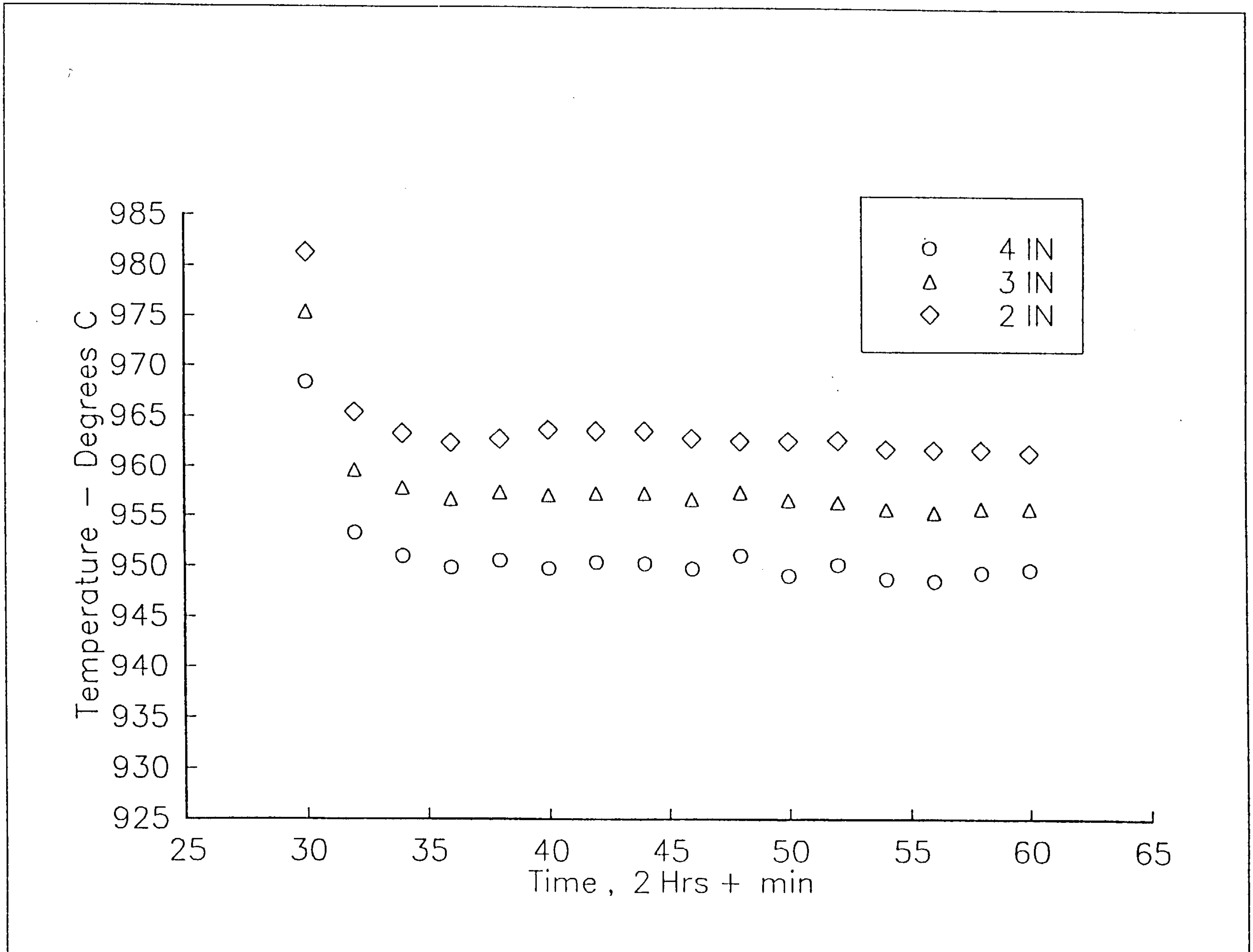


FIGURE: 9 TEMPERATURE CYCLE PROFILE ON FURNACE

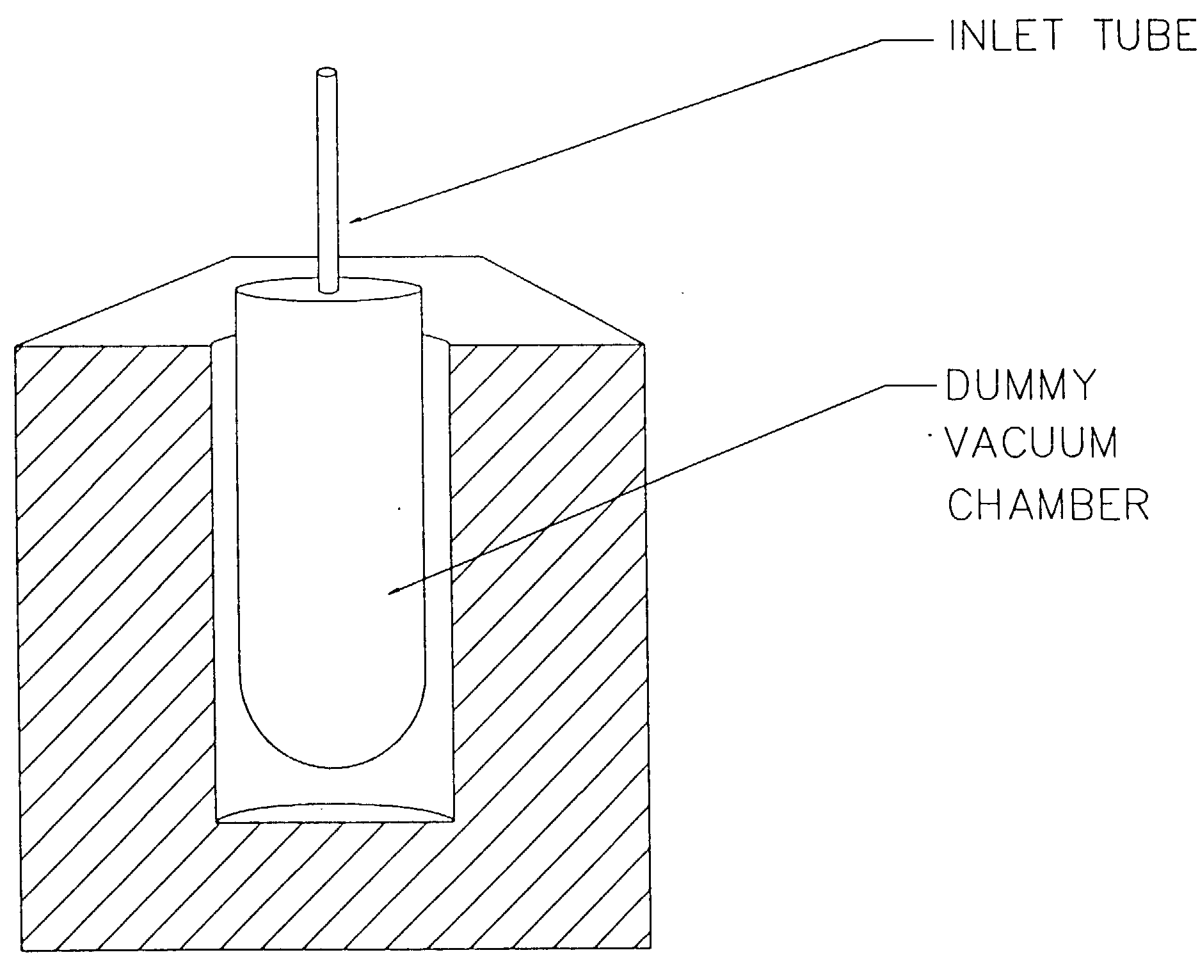


FIGURE 10: THERMAL HEAT LOAD TEST

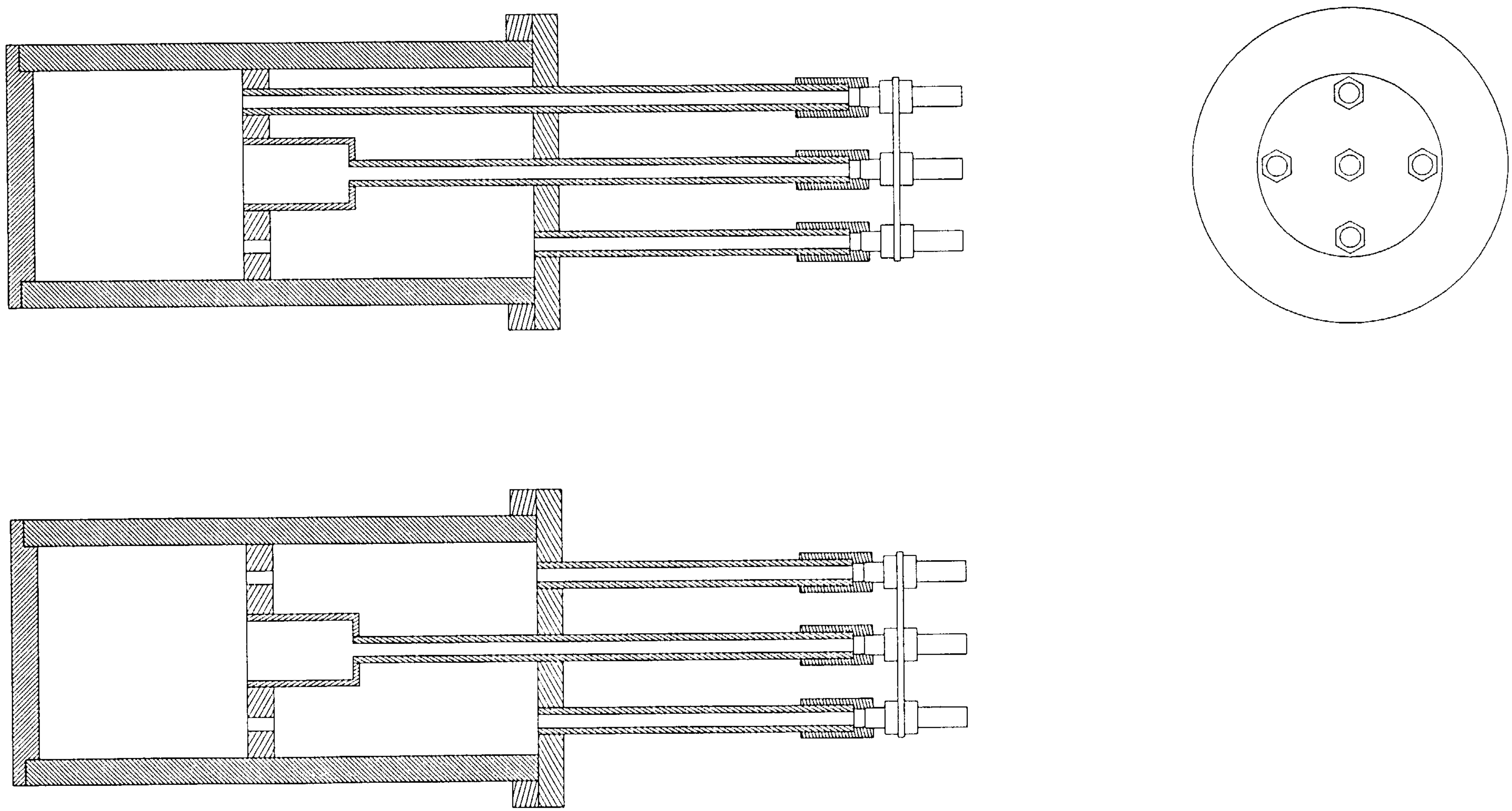


Figure 11: INITIAL DESIGN OF VACUUM CHAMBER ASSEMBLY

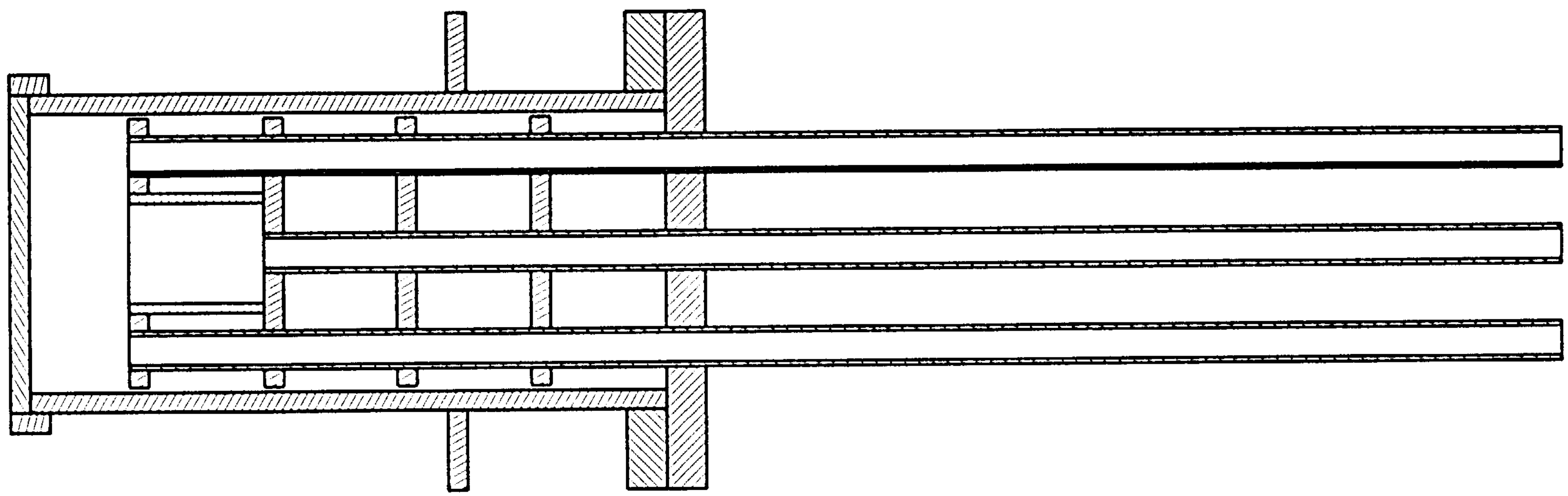


Figure 12: MODIFIED VACUUM CHAMBER DESIGN

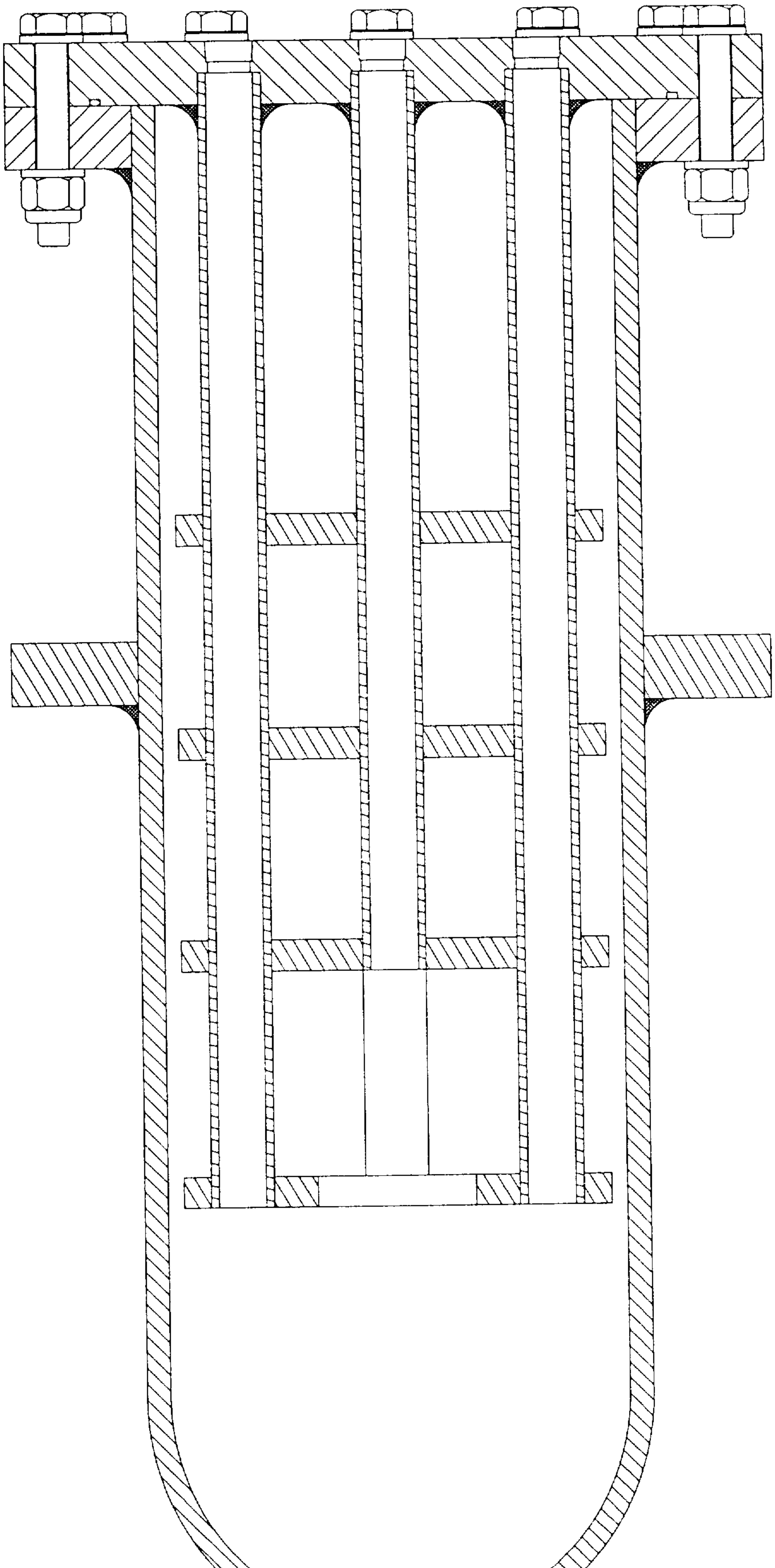


Figure 13: FINAL VACUUM CHAMBER DESIGN

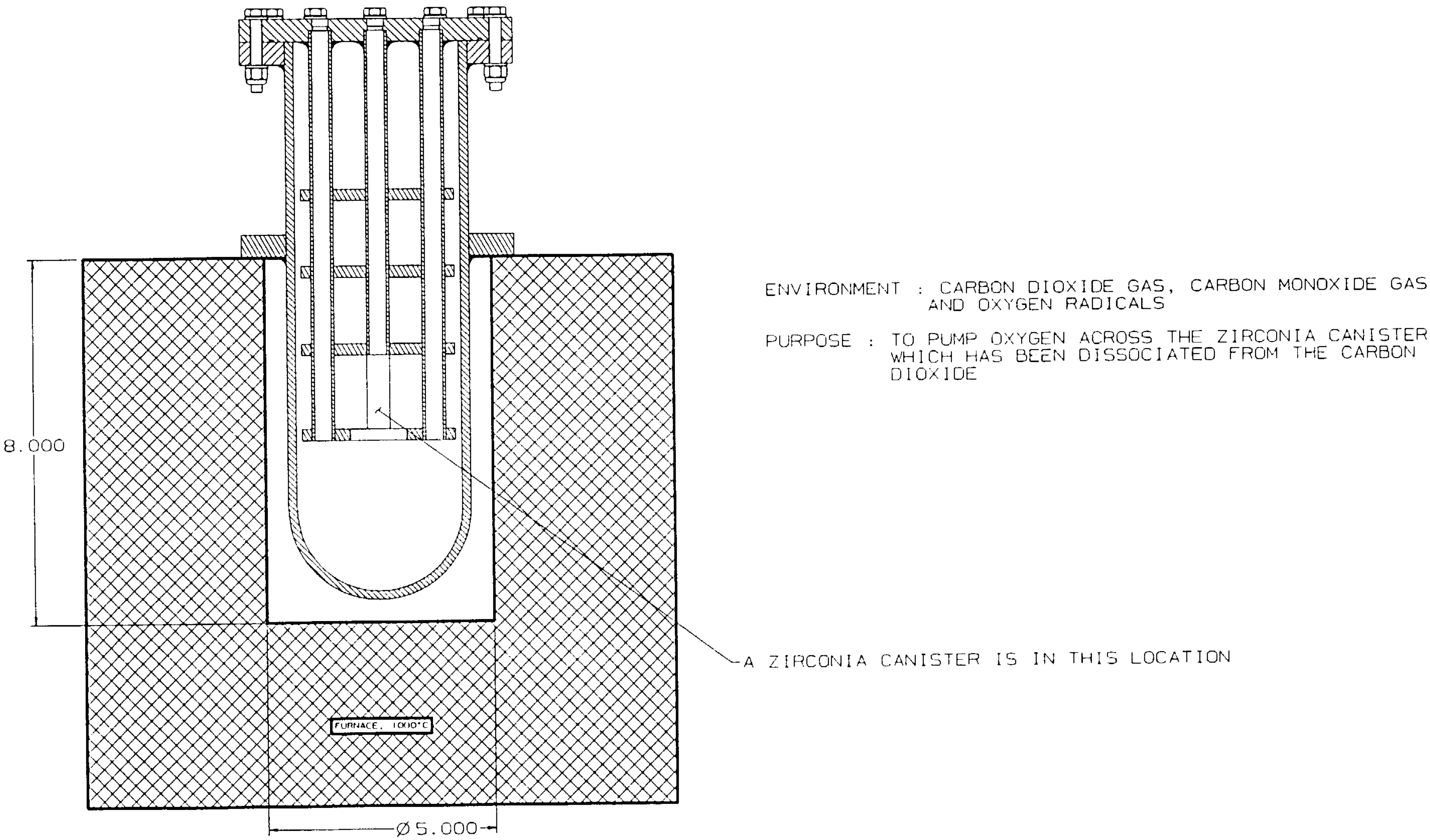
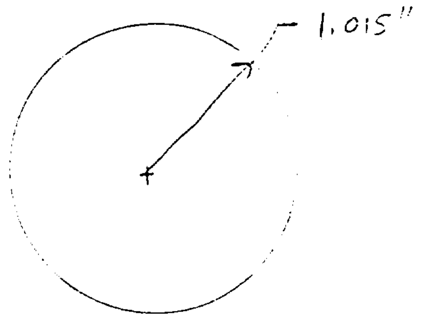


Figure 14: VACUUM CHAMBER AND FURNACE ASSEMBLY

APPENDIX A : CALCULATIONS

Keith Davis | Pressure on Zirconia Disk | January 27, 1993

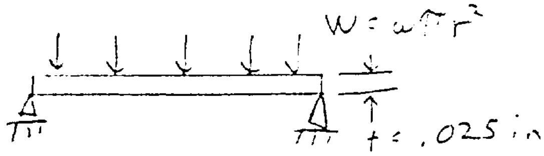
This calculation will estimate the maximum pressure differential allowed across the thin zirconia disk.



From Roark, 3rd ed. p.102

$$S_{max} = -\frac{3W\nu}{8\pi t^2}\left(\frac{3}{\nu}+1\right)$$

and occurs at the center of the disk



for zirconia, $\nu \simeq .22$ $\quad S_{max} \simeq 21$ Kpsi

$$W = \frac{-S_{max}(8\pi t^2)}{\left(\frac{3}{\nu}+1\right)3\nu}$$

$$= \frac{(21\times10^3\ psi)(8)(\pi)(.025\ in)^2}{\left(\frac{3}{.22}+1\right)(3)(.22)}$$

$W = 34$ lbs

$$\omega = \frac{W}{\pi r^2} = \frac{34\ lbs}{\pi(1.015\ in)^2}$$

$\omega = 10$ psi

let the factor of safety be 5.

then

$$\boxed{\Delta p_{max} = 2\ psi}$$

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From Suitor et al,

$S_u = 112.82$ MPa
E (Tensile modulus) $= 165.36$ GPa (24×10^6 psi)
$\alpha = 8.50 \times 10^{-6}$ in/in °F
Safety factor = 4

$$\sigma = \frac{S_u}{4} = \frac{112.82 \text{ MPa}}{4} = 28.205 \text{ MPa}$$

$$\sigma = \epsilon_T E$$

$$\epsilon_T = \frac{\sigma}{E} = \frac{28.205 \text{ MPa}}{165.36 \text{ GPa}} = 1.7057 \times 10^{-4}$$

$$\epsilon_T = \alpha \Delta T$$

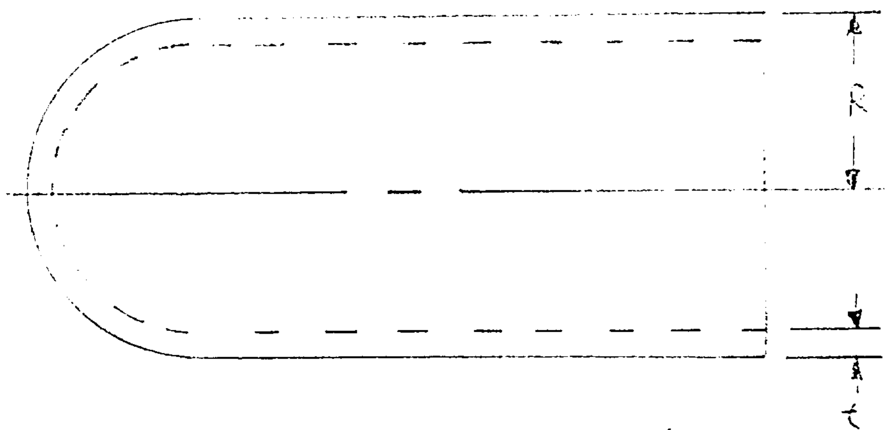
$$\Delta T = \frac{\epsilon_T}{\alpha} = \frac{1.7057 \times 10^{-4}}{8.50 \times 10^{-6}/°F}$$

$$\underline{\underline{\Delta T = 20.595 \text{ °F}}}$$

This is the maximum ΔT that the zirconia disk can withstand without any cracking during transient conduction.

42-381 50 SHEETS EYE-EASE® 5 SQUARE
42-382 100 SHEETS EYE-EASE® 5 SQUARE
42-389 200 SHEETS EYE-EASE® 5 SQUARE
42-392 100 RECYCLED WHITE 5 SQUARE
42-399 200 RECYCLED WHITE 5 SQUARE
Made in U.S.A.
National® Brand

This analysis will determine the maximum axial and circumferential stresses in the outer shell of the vacuum chamber



$R = 2.0$ in $\quad t = .188$ in

$\Delta p = -13.23$ psi $\quad \frac{R}{t} = 10.6 \simeq 10$

From Stress and Strain Data Handbook, Teng H. Hsu, Gulf Publishing Company, Houston, 1986, p 338. the equations for stress on a pressure vessel with hemispherical ends are:

$(\sigma_x)_{max} = \Delta p \, K_x$ (axial)

$(\sigma_t)_{max} = \Delta p \, K_t$ (circumferential)

$K_x \simeq 5$, $K_t \simeq 10$

$(\sigma_x)_{max} = (-13.23 \text{ psi})(5) = 67$ psi compression

$(\sigma_t)_{max} = (-13.23 \text{ psi})(10) = 133$ psi compression

Alumina is good for over 300 Kpsi in compression and 38 Kpsi in tension.

STRUCTURAL INTEGRITY IS NOT A PROBLEM!

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This analysis will attempt to estimate the heat loss required to cool a hot tube to an acceptable temperature at one end.

Assumptions:

1. the hot tube end is the same temp as the gas

2. the cold tube end is the same temp as the surrounding air

3. the coefficient of thermal conductivity is constant

$T_h := 1200 \cdot K$

$T_c := 300 \cdot K$

$T_{diff} := T_h - T_c$

$T_{diff} = 900 \cdot K$

$k := 4.113 \cdot \frac{watt}{m \cdot K}$ thermal conductivity of alumina at 700 K

$D_o := .5 \cdot in$

$D_i := .375 \cdot in$

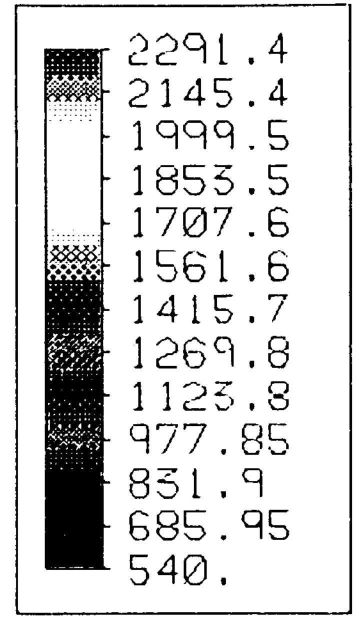
$A_c := \pi \cdot \frac{(D_o - D_i)^2}{4}$

$L := 10.75 \cdot in$

$q := k \cdot A_c \cdot \frac{T_{diff}}{L}$

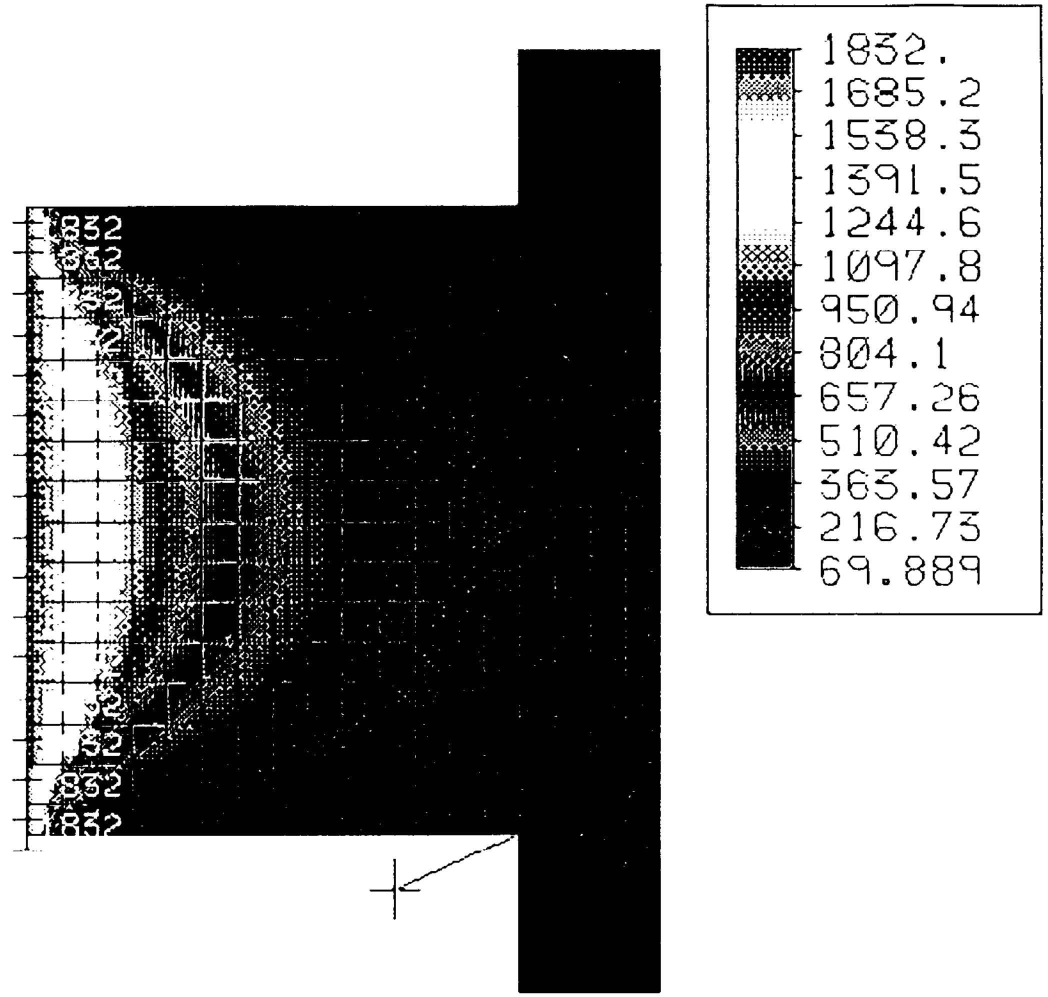
$q = 0.1073 \cdot watt$ the total heat that needs to be removed from the tube

◊ALGOR-V
GET VAL
[Esc]



1Help 2Undo
3Inp 4Snap
5Cur 6Swtc
7Big 8Menu
9Top 0Draw
Dither method = Temperature
Click on any node   Not just front nodes.
NODE #566: X=1.06554, Y=0.982766, Z=10.75: Temp=540
SVIEWT 1.06 File:M3 93/03/02 10:31   ST 1/ 1 Vu=U2 Lo=   0 La=   0 R= -90

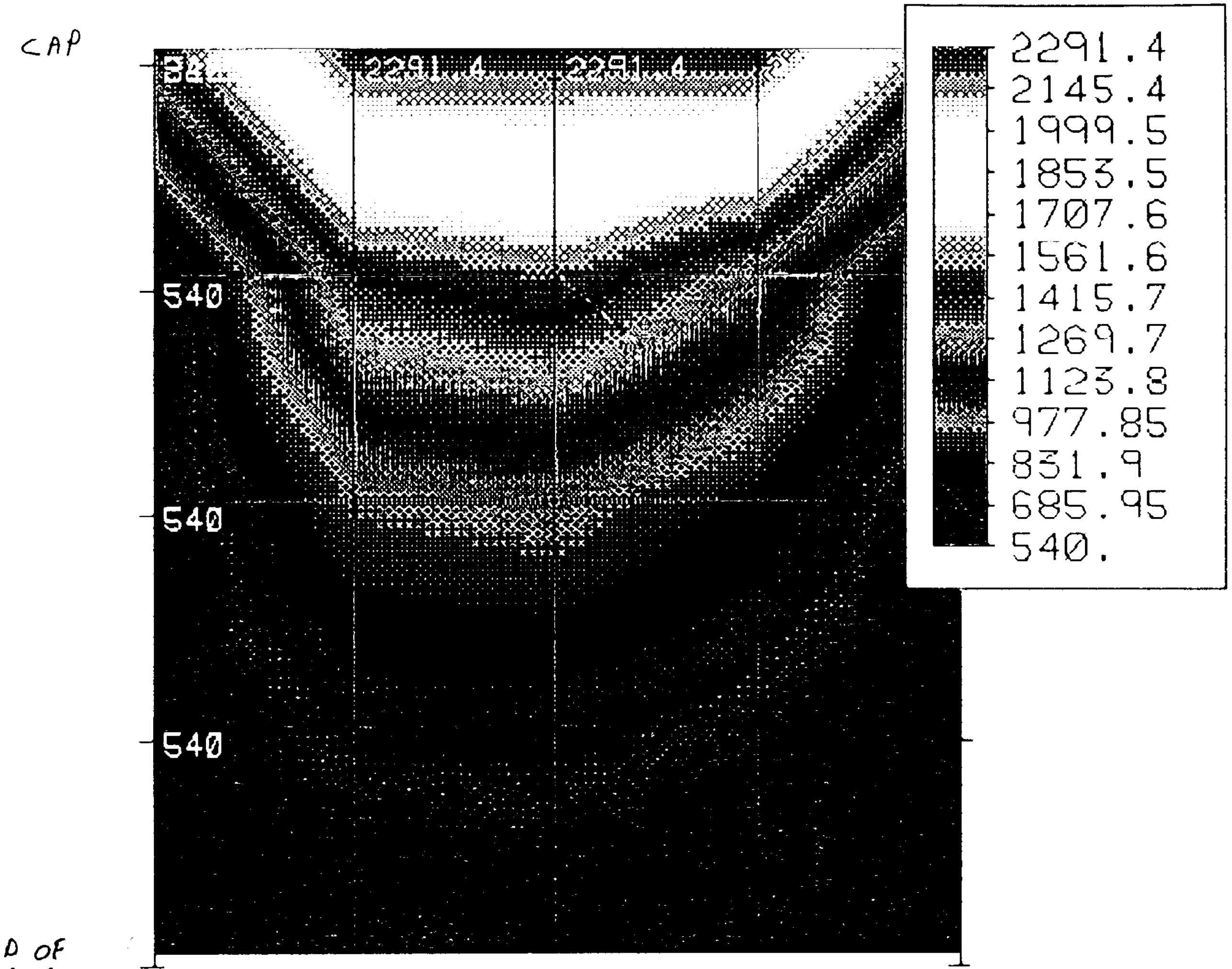
◇ALGOR-V
GET VAL
[Esc]



1Help2Undo
3Inp 4Snap
5Cur 6Swtc
7Big 8Menu
9Top 0Draw
Dither method = Temperature
Click on any node - Not just front nodes.
NODE #40: X=0, Y=12.5, Z=1: Temp=70.002
SVIEWT 1.06 File:MARS2 93/03/25 12:39   ST 1/ 1 Vu= 5 Lo= 90 La= 0 R= 0

Temperature profile of the exposed portion of the vacuum chamber

◊ALGOR-V
GET VAL
[Esc]



1Help 2Undo
3Inp 4Snap
5Cur 6Swtc
7Big 8Menu
9Top 0Draw
Dither method = Temperature
Click on any node - Not just front nodes.
NODE #18: X=0, Y=6.375, Z=9.0625: Temp=1531.5
SVIEWT 1.06 File:MIKE 93/02/24 10:07 ST 1/ 1 Vu= 5 Lo= 90 La= 0 R= 0

TEMPERATURE PROFILE OF AIR AROUND TUBES

(Produced on ALGOR with the assistance of Pete Hege, NASA Engineer)
[includes all of the following ALGOR plots]

APPENDIX B : INFORMATION ON CERAMIC ADHESIVES

SECTION I - PRODUCT IDENTIFICATION

Manufacturer: Aremco Products, Inc.
23 Snowden Ave.
Ossining, NY 10562

Information Phone: 914 762 0685
Emergency Phone: 914 762 0685
914 941 5177
914 941 6609

IDENTITY: PyroPutty 600

05/1/91

SECTION II - HAZARDOUS INGREDIENTS/IDENTITY INFORMATION

Hazardous Compounds	CAS #	ACGIH TLV
Aluminum oxide	1344-28-1	10mg/m3
Silicate Solution	1312-76-1	N/D
Silica	7631-86-9	10mg/m3

Note: All powders are blended in a liquid solution preventing any free dust.

SECTION III - PHYSICAL DATA

Boiling Point: 200 F

Specific Gravity: 2.7

Vapor Density (AIR=1): N/A

Melting Point: 3053 F

Vapor Pressure (mm Hg.): N/A

Evaporation Rate: 0
(Butyl Acetate=1)

Solubility in Water: 70%

Appearance and Odor: White odorless paste

SECTION IV - FIRE and EXPLOSION HAZARD DATA

Flash Point: Nonflammable

Flammable Limits: LEL: (N/A) UEL: (N/A)

Extinguishing Media: Non-combustible

Special Fire Fighting Procedures: None

Unusual Fire and Explosion Hazards: None

SECTION V - REACTIVITY DATA

Stability ( ) Unstable (X) Stable

Conditions to avoid: None

Hazardous Polymerization ( ) May Occur (X) Will Not Occur

SECTION VI - HEALTH HAZARD DATA

Effects of Overexposure

Inhalation: Low health risk by inhalation.

Ingestion: There is no toxicity by ingestion.

Dermal exposure: Not an irritant.

Eye irritation: Not an irritant.

Emergency and First-Aid Procedures

No specific first aid procedures are necessary for accidental exposure to this product. Maintain a good standard of industrial hygiene and housekeeping.

SECTION VII - PRECAUTIONS FOR SAFE HANDLING AND USE

Steps to be taken in case material is released or spilled: Use dry clean-up procedures. Collect in containers or bags. Wash residue with soap and water. If recycling is not possible, may be disposed of at a sanitary landfill.

Waste Disposal Method: Dispose of in accordance with local, state, and federal regulations.

Precautions to be taken in handling and storing: Impervious gloves, safety goggles, and proper ventilation.

SECTION VIII SPECIAL PROTECTION INFORMATION

Good industrial hygiene practice requires that employee exposure be maintained below the recommended TLV. This is preferably achieved through the provision of adequate ventilation where necessary. Where dust cannot be controlled in this way, personal respiratory protection should be employed.

CHEMICAL COMPONENTS OF THIS PRODUCT WHICH ARE PRESENT IN REPORTABLE AMOUNTS AND ARE LISTED IN SECTION 313 OF THE EMERGENCY PLANNING AND COMMUNITY RIGHT TO KNOW ACT OF 1986 (SARA TITLE III) ARE SHOWN BELOW WITH THEIR CAS REGISTRY NUMBERS AND MAXIMUM COMPOSITION BY WEIGHT.

LISTED CHEMICAL	CAS NUMBER	MAX WT %
NONE		

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SECTION I - PRODUCT IDENTIFICATION

Manufacturer: Aremco Products, Inc.
23 Snowden Ave.
Ossining, NY 10562

Information Phone: 914 762 0685
Emergency Phone: 800-535-5053

IDENTITY: Cerama-Bond 503

11/11/92

SECTION II - IDENTITY INFORMATION/HAZARDOUS INGREDIENTS

Compound	CAS #	ACGIH TLV	Weight %
Aluminum Oxide	1344-28-1	10 mg/m3	<70
Phosphoric Acid	7664-38-2	2 mg/m3	<4

*NOTE: The above listed compound is suspended in an inorganic binder system, therefore no free dust exists.

SECTION III - PHYSICAL DATA

Boiling Point: 212 F

Specific Graviy: 2.1

Vapor Density (AIR=1): No Data

Melting Point: No Data

Vapor Pressure (mm Hg.): No Data

Evaporation Rate: No Data
(Butyl Acetate=1)

Solubility in Water: 50%

V.O.C. content: 0 gm/ltr.

Appearance and Odor: Odorless, white viscous liquid.

SECTION IV - FIRE and EXPLOSION HAZARD DATA

Flash Point: No Data

Flammable Limits LEL: No Data UEL: No Data

Extinguishing Media: Not Flammable

Special Fire Fighting Procedures: Use self contained air supplied breathing apparatus, and impervious protective clothing.

Unusual Fire and Explosion Hazards: Not considered a fire hazard and does not support combustion. When involved in a fire, does not contribute any unusual fire hazards.

SECTION V - REACTIVITY DATA

Stability ( ) Unstable (X) Stable

Conditions to avoid: Acidic in nature and reacts with bases, such as carbonates, oxides and hydroxides of alkali metals, to form insoluble hydrates of aluminum phosphate.

This material is corrosive to common metals such as mild steel, copper, brass, and bronze.

Hazardous Polymerization ( ) May Occur (X) Will Not Occur

SECTION VI - HEALTH HAZARD DATA

Effects of Overexposure

Inhalation: There are no known data available which address medical conditions that are generally recognized as being aggravated by exposure to this product.

Dermal exposure: Contact with skin may result in irritation or burns.

Eye irritation: Contact with eyes may result in irritation or burns.

Ingestion: May cause stomach pains and nausea.

Emergency and First-Aid Procedures

Eye - Immediately flush with large quantities of water for at least 15 minutes. Obtain medical attention as soon as possible. Oils or ointments should not be used at this time.

Skin - Flush affected areas with plenty of water for several minutes. Seek medical attention if skin irritation occurs.

Ingestion - Give several glasses of water but do not induce vomiting. if vomiting does occur, give fluids again. Seek medical attention immediately. Do not give anything by mouth to an unconscious or convulsing person.

Inhalation - Remove to fresh air. Get medical attention.

SECTION VII - PRECAUTIONS FOR SAFE HANDLING AND USE

Steps to be taken in case material is released or spilled: neutralize the spill area with soda ash and then flush area with copious amounts of water. Exercise caution during the neutralization as considerable heat may be generated.

Waste Disposal Method: Dispose of in accordance with local, state, and federal regulations.
Precautions to be taken in handling and storing: Containers should be stored in a cool, dry, well ventilated area away from flammable materials and sources of heat or flame. Exercise due caution to prevent damage to or leakage from the container.

SECTION VIII SPECIAL PROTECTION INFORMATION

Use NIOSH approved mist respirator where spray occurs. Use of impervious rubber gloves and chemical goggles is recommended.

Good industrial hygiene practice requires that employee exposure be maintained below the recommended TLV. This is preferably achieved through the provision of adequate ventilation where necessary. Where dust cannot be controlled in this way, personal respiratory protection should be employed.

CHEMICAL COMPONENTS OF THIS PRODUCT WHICH ARE PRESENT IN REPORTABLE AMOUNTS AND ARE LISTED IN SECTION 313 OF THE EMERGENCY PLANNING AND COMMUNITY RIGHT TO KNOW ACT OF 1986 (SARA TITLE III) ARE SHOWN BELOW WITH THEIR CAS REGISTRY NUMBERS AND MAXIMUM COMPOSITION BY WEIGHT.

LISTED CHEMICAL	CAS NUMBER	MAX WT %
NONE		

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Manufacturer: Aremco Products, Inc.
23 Snowden Ave.
Ossining, NY 10562

Information Phone: 914 762 0685
Emergency Phone: 914 762 0685
914 941 5177
914 941 6609

IDENTITY: Ceramabond 571 Powder 09/24/90

SECTION II - HAZARDOUS INGREDIENTS/IDENTITY INFORMATION

Hazardous Compounds	CAS #	ACGIH TLV	Weight %
Magnesium oxide	1309-48-4	10 mg/m3	<90
Aluminum oxide	1344-28-1	10 mg/m3	<20

SECTION III - PHYSICAL DATA

Boiling Point: No Data

Specific Gravity: No Data

Vapor Density (AIR=1): No Data

Melting Point: No Data

Vapor Pressure (mm Hg.): No Data

Evaporation Rate: No Data
(Butyl Acetate=1)

Solubility in Water: Slightly soluble

V.O.C. Content: 0 gm/ltr.

Appearance and Odor: Odorless white powder.

SECTION IV - FIRE and EXPLOSION HAZARD DATA

Flash Point: No Data Flammable Limits LEL: No Data UEL: No Data

Extinguishing media: Not Flammable

Special Fire Fighting Procedures: Use self contained air supplied breathing apparatus.

Unusual Fire and Explosion Hazards: None

SECTION V - REACTIVITY DATA

Stability ( ) Unstable (X) Stable
Conditions to avoid: Strong oxidizers, interhalogens, phosphorus pentachloride, chlorine trifluoride. If magnesium oxide is heated to the point of volatilization, magnesium oxide fume may be generated.

Hazardous Polymerization ( ) May Occur (X) Will Not Occur

SECTION VI - HEALTH HAZARD DATA

Effects of Overexposure

Inhalation: Inhalation of MgO and Al2O3 can produce respiratory irritation with resulting edema and difficulty in breathing. If MgO is heated to the point of volatilization, MgO fumes may be generated. Exposure to MgO fume can produce metal fume fever, an illness similar to influenza. The symptoms of this illness include fever, cough oppression in the chest, nausea, vomiting, headache, muscular pain and leukocytosis. Inhalation of MgO dust and fume may aggravate symptoms for persons suffering from chronic respiratory diseases.

Dermal exposure: Not a skin irritant.

Eye irritation: Slightly irritating.

Ingestion: Generally, MgO is an antacid and is so slowly absorbed that oral administration causes nothing more than purging. If evacuation fails to occur irritation of the mucous membranes and absorption can occur. Systemically, it can produce dizziness, diarrhea, nausea, vomiting, depression of the muscular contraction and respiratory paralysis.

Emergency and First-Aid Procedures

Eye - Immediately flush eyes with plenty of water for at least 15 minutes. Call a physician.

Skin - Not applicable.

Ingestion - Not applicable.

Inhalation - Remove to fresh air.

SECTION VII - PRECAUTIONS FOR SAFE HANDLING AND USE

Steps to be taken in case material is released or spilled: Normal clean-up procedures. Care should be taken to avoid causing dust to become airborne. Do not flush to sewer.

Waste Disposal Method: Dispose of in accordance with local, state, and federal regulations.

Precautions to be taken in handling and storing: Avoid causing dust to become airborne.

SECTION VIII SPECIAL PROTECTION INFORMATION

Use NIOSH approved mist respirator where spray occurs. Use of rubber gloves and chemical goggles is recommended.

Good industrial hygiene practice requires that employee exposure be maintained below the recommended TLV. This is preferably achieved through the provision of adequate ventilation where necessary. Where dust cannot be controlled in this way, personal respiratory protection should be employed.

CHEMICAL COMPONENTS OF THIS PRODUCT WHICH ARE PRESENT IN REPORTABLE AMOUNTS AND ARE LISTED IN SECTION 313 OF THE EMERGENCY PLANNING AND COMMUNITY RIGHT TO KNOW ACT OF 1986 (SARA TITLE III) ARE SHOWN BELOW WITH THEIR CAS REGISTRY NUMBERS AND MAXIMUM COMPOSITION BY WEIGHT.

LISTED CHEMICAL	CAS NUMBER	MAX WT %
NONE		

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SECTION I - PRODUCT IDENTIFICATION

Manufacturer: Aremco Products, Inc.
23 Snowden Ave.
Ossining, NY 10562

Information Phone: 914 762 0685
Emergency Phone: 914 762 0685
914 941 5177
914 941 6609

IDENTITY: Ceramabond 571 Liquid 09/24/90

SECTION II - IDENTITY INFORMATION/HAZARDOUS INGREDIENTS

Compound	CAS #	ACGIH TLV	Weight %
Silicate Solution	6834-92-0	N/D	100

SECTION III - PHYSICAL DATA

Boiling Point: 212 F

Specific Gravity: 1.4

Vapor Density (AIR=1): 0.6

Melting Point: No Data

Vapor Pressure (mm Hg.): 17.0

Evaporation Rate: (1.00 (Butyl Acetate=1)

Solubility in Water: Complete

V.O.C. Content: 0 gm/ltr.

Appearance and Odor: Odorless, colorless to hazy liquid.

SECTION IV - FIRE and EXPLOSION HAZARD DATA

Flash Point: No Data

Flammable Limits: LEL: No Data UEL: No Data

Extinguishing Media: Not Flammable

Special Fire Fighting Procedures: Use self-contained air supplied breathing apparatus, and impervious protective clothing.

Unusual Fire and Explosion Hazards: Not considered a fire hazard and does not support combustion. When involved in a fire, does not contribute any unusual hazards.

SECTION V - REACTIVITY DATA

Stability: ( ) Unstable (X) Stable
Conditions to avoid: Flammable hydrogen gas may be produced on prolonged contact with metals such as aluminum, tin, lead, and zinc, in an alkaline environment.
Incompatibility: Gels when mixed with acid.

Hazardous Polymerization: ( ) May Occur (X) Will Not Occur
Hazardous Decomposition or By Products: Hydrogen - see "Conditions to Avoid".

SECTION VI - HEALTH HAZARD DATA

Effects of Overexposure

Inhalation: Causes irritation to the respiratory tract; may cause sneezing, burning, or itching in nose and throat. May aggravate asthma and lung diseases.

Dermal exposure: Causes skin irritation; may cause itching and burning of skin.

Eye irritation: Causes eye irritation; may cause pain, redness, and tearing. May aggravate any existing skin diseases.

Ingestion: Causes irritation to the esophagus and stomach, may cause nausea, vomiting, and diarrhea.

Emergency and First-Aid Procedures

Inhalation - Remove to fresh air, consult a physician if necessary.

Skin - Thoroughly wash exposed area with soap and water. Remove contaminated clothing, and launder before re-use.

Eye - Flush with large amounts of water, lifting upper and lower lids occasionally, get medical attention.

Ingestion - Immediately drink two glasses of water and induce vomiting by either giving Ipecac syrup or by placing finger at back of throat. Never give anything by mouth to an unconscious person. Get medical attention immediately.

SECTION VII - PRECAUTIONS FOR SAFE HANDLING AND USE

Steps to be taken in case material is released or spilled: Isolate, dike and store discharged material, if possible. Otherwise disperse and flush with water, observing environmental protection regulation.

Waste Disposal Method: Dispose of in accordance with local, state, and Federal regulations.

SECTION VIII SPECIAL PROTECTION INFORMATION

Use NIOSH approved mist respirator where spray occurs. Use of rubber gloves and chemical goggles is recommended.

Good industrial hygiene practice requires that employee exposure be maintained below the recommended TLV. This is preferably achieved through the provision of adequate ventilation where necessary. Where dust cannot be controlled in this way, personal respiratory protection should be employed.

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CERAMABOND™ HI-PERFORMANCE CERAMIC ADHESIVES

Aremco's high temperature ceramic adhesives are unique asbestos-free, inorganic-based bonding materials for use at temperatures to 3200° F. The Ceramabond family of adhesives can be used to bond a myriad of materials including, ceramics, metals, glass, graphites and composites. Ceramabond adhesives are used in OE M as well as industrial processes and maintenance/repair operations. These materials have been designed to accomodate a range of design criteria including, coefficient of thermal expansion, electrical resistivity, adherence, viscosity, fill capability, and mechanical strength.

TYPICAL BONDING APPLICATIONS FOR PRODUCTION AND R & D

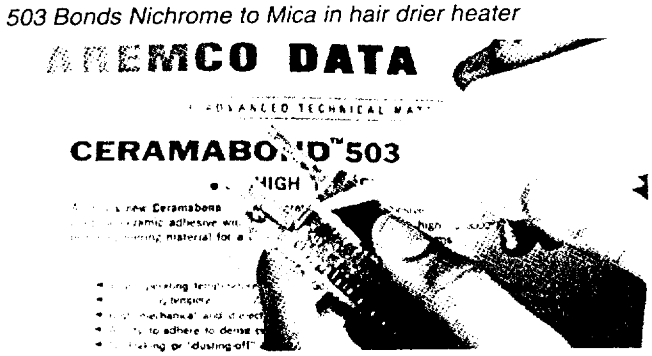
INDUSTRY	APPLICATION	INDUSTRY	APPLICATION
Appliance	Ceramic-to-metal gas igniters Sealing gaskets Heating elements	**Chemical/Ceramic Metal Processing**	Kiln insulation Bonding furnace parts Graphite parts attachment Ceramic textile insulation
Aerospace	Thermocouple attachment Structural insulation Threadlocking	**Communication**	Fiber optics High temperature feed-thrus
Automotive	Engine performance sensors Engine components Threadlocking Catalytic convertors	**Power Plants**	Sealing furnace doors Hi-temp pump repairs Refractory repair Gasket sealing/attachment Strain gauge bonding Cementing insulation board

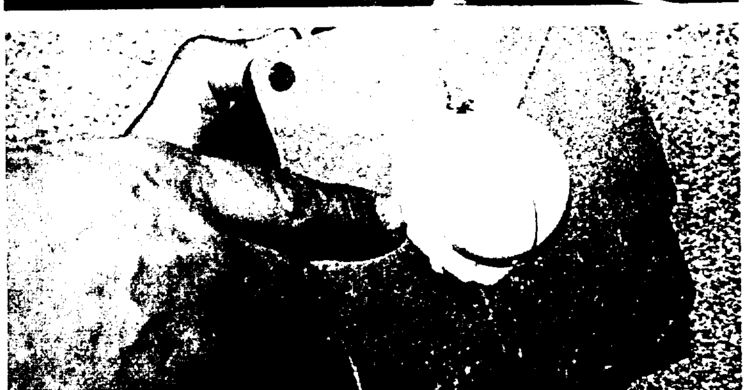
This represents only a sampling of ceramic adhesive applications. Ask for product application news bulletins.

APPLICATIONS

671 Used as HI-Temp Thread Locking Adhesive

503 Bonds Nichrome to Mica in hair drier heater





571 Bonds Mullite Cap to steel base in Oxygen Analyzer

Graphite Seal Rings Bonded with 669

SEE INSIDE AND BACK FOR TECHNICAL DATA .

AREMCO PRODUCTS, INC.
P.O. BOX 429, OSSINING, NEW YORK 10562
FAX: (914) 762-1663 • PHONE: (914) 762-0685

AREMCO HIGH TEMPERATURE CERAMIC ADHESIVE PROPERTIES

Product No.	503	516	551-R	552	569[1]	571	618	632	633	668	669	670	671
Trade Name	Ceramabond	Ultra-Temp	Graphi-Bond	Ceramabond	Ceramabond	Ceramabond	Ceramabond	Ceramabond	Ceramabond	Ceramabond	Graphi-Bond	Ceramabond	Ceramabond
Description	Bonds well to ceramics and glass. Works inside vacuum systems	Bonds well to zirconia & silicon	Bonds Graphite for use in reducing atmospheres	Bonds ceramic to metal for gasketing applications	No temperature cure needed. Good moisture resistance	High CTE permits bonds to steel, copper, aluminum	Bonds low expansion ceramics	Bonds glass bonded mica, glass/ceramics	Bonds alumino silicate ceramics	Viscous adhesive for heavy sections	Bonds graphite in air also acts as putty	Bonds silica textiles & porous ceramics	Hi-strength thread locking adhesive
Major Constituent	Alumina	Zirconia	Graphite	Alumina	Alumina	Magnesia	Silica	Mica	Alumino-Silicate	Alumina	Graphite	Alumina	Alumina
Temperature Limit° F	3000	3200	5400[4]	3000	3000	3200	1850	1200	2100	2500	2500	3200	3200
Temperature Limit° C	1650	1760	2985[4]	1650	1650	1760	1000	650	1150	1371	1371	1760	1760
No. Components	1	1	1	1	1	2	1	1	1	1	1	1	1
Dispensable	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Relative Viscosity CPS	30-40M	20-30M	Paste	37-50M	90M+	50-60M	30-40M	15-25M	20-30M	90M+	90M+	30-40M	40-50M
CTE in/°F x 10^{-6}	4.0	4.1	4.1	4.3	4.2	7.0	.33	5.0	3.0	4.0	4.2	3.0	4.1
CTE in/°C x 10^{-6}	7.2	7.4	7.4	7.7	7.6	12.6	.59	9.0	5.4	7.2	7.6	5.4	7.4
Volume Resistivity (ohm-cm @ RT)	10^9	10^6	NA	10^8	10^9	10^9	10^9	10^8	10^9	10^8	10^4	10^8	10^8
Volume Resistivity (ohm-cm @ 1000° F)	10^5	10^4	NA	10^4	10^5	10^5	10^5	10^4	10^4	10^4	10^4	10^4	10^4
Thermal Conductivity (BTU-in / hr-ft²-° f)	48.8	16.3	120.0	49.8	54.3	75.6	3.9	4.8	7.9	34.8	160.9	21.4	54.3
Dielectric Strength (volts per mil @ RT)	253	250	NA	250	256	255	200	250	80	245	NA	200	250
Dielectric Strength (volts per mil @ 1000° F)	240	80	NA	80	100	100	180	200	60	95	NA	180	97
Torque Strength ft-lbs	5.6	8.6	NA	6.7	5.6	22.3	5.2	10.0	4.1	10.6	2.1	3.0	24.3
Hardness (Moh's Scale)	6	6.5	4.0	7	6	5.5	4	3	5	9	6	4	9
Porosity (after curing)%	< 1	< 1	< 1	< 1	< 1	< 1	< 1.8	< 1	< 3	< 1	< 1	< 2	< 1
Moisture Resistance	Good after 700° F firing	Good	Excellent after 250° F cure	Excellent after 700° F firing	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Oxidation Resistance	Excellent	Excellent	Poor Above 700° F	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Good	Excellent	Excellent
Alkali Resistance	Fair	Excellent	Good	Excellent	Excellent	Excellent	Good	Good	Good	Excellent	Good	Good	Excellent
Acid Resistance	Excellent attacked by HF	Good-Attacked By HF & H_2SO_4	Good	Good-attacked by conc.HF	Excellent attacked by HF	Fair - attacked by HF	Good	Good	Good	Good attacked by HF	Good	Good	Good attacked by HF
Solvent Resistance (organic)	Excellent	Excellent	Good	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Good	Excellent	Excellent
Shelf Life[3]	6mos.	6mos	6mos @ 40° F 1 mo @ >80° F	6mos	6mos.	6mos.	6mos.	6mos.	6mos.	6mos.	6mos.	6mos.	6mos.
Cure Guide	Air Dry +Heat	Air Dry +Heat	Air Dry +Heat	Air Dry +Heat	Air Dry	Air Dry +Heat	Air Dry +Heat	Air Dry +Heat	Air Dry +Heat	Air Dry +Heat	Air Dry +Heat	Air Dry	Air Dry +Heat
Color	White	Tan	Black	White	White	Beige	White	Tan	Gray	White	Black	White	White
Density (lbs./gallon)	20	19	13	18	18	13-Powder 11-Liquid	16	12	12	18	13	17	19

Notes: ① 569-FR (Fiber Reinforced) Higher Strength Version is also available. ② Thinners are available to alter viscosity. Refer to application procedures. ③ Shelf life can be extended by nitrogen packaging. Consult Aremco. ④ Temperature limit for 551-R is for reducing atmosphere only. ⑤ Thermal Conductivity measured for cured adhesive at approximately 900 °F

CERAMIC ADHESIVE SELECTOR CHART

MATERIAL	CTE x 10^{-6} in / °F	CTE x 10^{-6} in / °C	503	516	551-R	552	569	571	618	632	633	668	669	670	671
ALUMINUM	15.01	27.0						•							
BRASS	10.2	18.4						•							
COPPER	9.3	16.7						•							
INCONEL	6.4	11.5		X		X	•	X		X					
CAST IRON	5.9	10.6		X		X	X	•							
MOLYBDENUM	2.9	5.2		X		X	•		X		X		X		
NICKEL	7.2	12.9		X		X	X	•							
NICKEL-IRON	2.6	4.7		X		•	X	X			X				
PLATINUM	4.9	8.8	X	X		X	•	X		X					
SILICON	1.6	2.9	X	•		X	X								
SILVER	10.6	19.1						•							
STAINLESS STEEL (300 SERIES)	9.6	17.3		X		X	X	•							
STAINLESS STEEL (400 SERIES)	6.2	16.6						•				X	X		
STEEL (1010)	6.5	11.7		X		X	X	•							•
TANTALUM	3.9	7.0	X	X		X	•	X		X		X	X		
TITANIUM	5.8	10.4					X	•				X			
TUNGSTEN	2.5	4.5		X		X	•		X	X					
ALUMINA (96%)	4.4	7.9	•	X		X	X	X				•			
ALUMINUM NITRIDE	2.5	4.5					•		X			X			
BERYLLIA (95%)	4.1	7.4	•	X		X	X	X							
BORON CARBIDE	2.55	4.6					•		X						
BORON NITRIDE	4.17	3.8	•	X		X	X								
CORDIERITE	1.1	1.9							•						
GLASS (Borosilicate)	1.8	3.2	•	X		X	X		X						
GRAPHITE	4.3	7.7	X	X	•							X	•		
MACOR®	5.2	9.4					X	X		•					
GLASS BONDED MICA	5.8	10.4						X		•					
MULLITE	3.0	5.4	•				X								
QUARTZ	.31	.56	X				X		•						
SAPPHIRE	4.2	7.6	•	X		X	X	X		X					
SILICA / ALUMINA TEXTILES	NA	NA												•	
STEATITE	3.99	7.2	•	X		X	X			X					
SILICON CARBIDE	2.9	5.2	•									X			
SILICON NITRIDE	1.8	3.2							X		•				
AREMCOLOX™ MACHINABLE CERAMICS															
502-400/-600	6.0 / 5.2	10.8/9.3								•					
502-1100	2.9	5.22									•				
502-1200/-1250	0/.3	0/.16							•						
502-1400	4.4	6.3	•				X	X							

• Preferred Product For This Application

x Applicable Product For This Application

NOTE: Use this chart as a guide only. Other factors such as environment, temperature cycle, parts size, clearance between parts, etc. will effect end results. See back page for design considerations.

Density (lbs./gallon)

19, 17, 13, 18, 12, 12, 16, 15-Powder 11-Liquid, 18, 18, 13, 19, 20

Notes: ① 569-FR (Fiber Reinforced) Higher Strength Version is also available. ② Thinners are available to alter viscosity. Refer to application procedures. ③ Shelf life can be extended by nitrogen packaging. Consult Aremco.
④ Temperature limit for 551-R is for reducing atmosphere only. ⑤ Thermal Conductivity measured for cured adhesive at approximately 900 °F

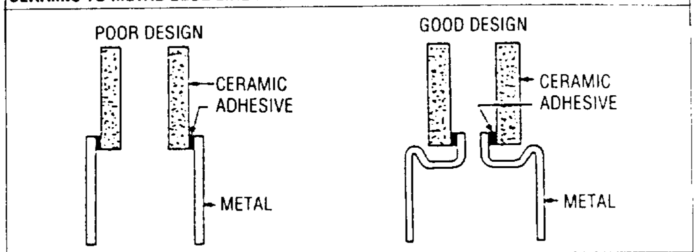
DESIGN CONSIDERATIONS USING AREMCO CERAMIC ADHESIVES

General design criteria for bonding with ceramic adhesives are similiar to those for epoxies and other organic adhesives. Main considerations include coefficient of thermal expansion, joint stress analysis, glue line thickness, environmental factors, and adhesive property limitations.

Coefficient of Thermal Expansion

Due to the thermal shock implicit in most ceramic adhesives applications, the joint design should account for the difference in CTE between the adhesive and the components that are being joined. In the illustration note that the "poor" design loads the ceramic adhesive in tension since the metal expands faster than the ceramic. The "good" design allows for this thermal mis-match which maximizes the ceramic adhesive's ability to take compressive loading, offering higher reliability.

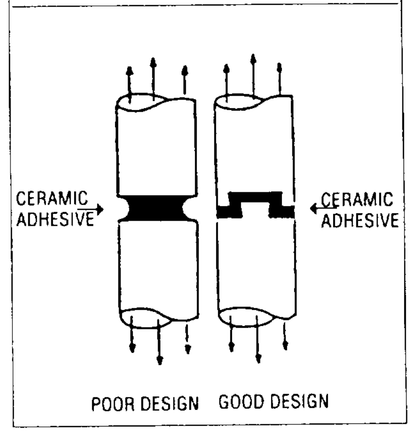
CERAMIC TO METAL GLUE LINE DESIGN



Joint Stress Analysis

Since ceramic adhesives exhibit relatively poor tensile and shear strength, it is desirable to change the configuration of the glue line to distribute the stress. A longer glue line should be designed to reduce joint stress.

CERAMIC-TO-CERAMIC RECOMMENDED GLUE LINE DESIGN



Glue Line Thickness

The clearance between mating parts (calculated at operating temperature) should be .002"–.008". Less than .002" will prevent uniform adhesion, and greater than .008" will often result in cohesive shear failure within the adhesive.

Environmental Factors

Ceramic adhesives behave well in a high vacuum environment. In contrast to organic adhesives, most ceramics will not outgas after they are temperature cured. Other factors such as corrosive conditions, electrical requirements, humidity, and cure temperature limitations should be considered.

Ceramic Property Limitations

Ceramic adhesives are somewhat brittle and may be affected by dynamic conditions such as vibration and mechanical shock. Expansion joints can be used to relieve stress. Adding ceramic cloth at the interface is also useful. Note that porous surfaces will absorb liquid binders. Impregnate surface with appropriate thinner before using the adhesive.

Do not hesitate to contact Aremco's sale engineers for specific recommendations for your application.

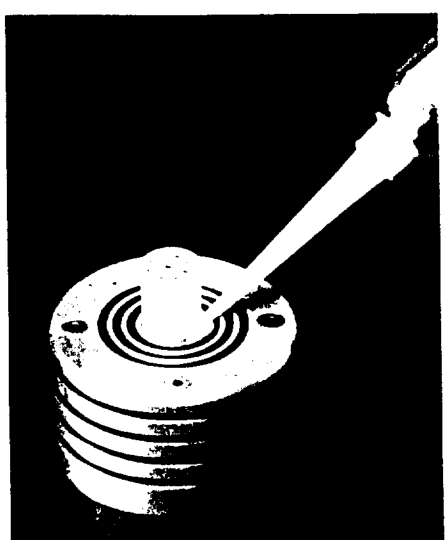
METHODS OF APPLYING AREMCO CERAMIC ADHESIVES

Methodology

Ceramic adhesive can be applied by paint, brush, spatula, dipping, screen printing, syringe, caulking or automatic dispensing. Ask for recommendations.

Cure Temperatures

Refer to the Application Procedures Bulletin (AP-2) for each material. Frequently a low temperature cure at 250° F (121° C) will suffice using conventional bakeout ovens, radiant heat, or even heat guns.



Assembly Methods

It is important to maintain a uniform glue line during the setting period using fixtures or spring clamps.

Be sure to refer to Application Procedures Bulletin AP-2, and MSDS data before using these products. Also ask for price lists and information on ceramic adhesive kits.

Aremco Products, Inc. makes no warranty express or implied concerning the use of this product. The user assumes all risk of use or handling whether or not in accordance with directions or suggestions, or used singly or in combination with other products.

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FAX: (914) 762-1663 • PHONE: (914) 762-0685

CERAMABOND™ 503, 551-R, 552, 569, 571, 618, 632, 633, 668, 670, 671 ULTRA-TEMP™ 516 AND GRAPHI-BOND™ 669

A) SURFACE PREPARATION AND APPLICATION:

1) All surfaces to be bonded or coated should be free of dirt, grease or oil. When possible roughen surfaces. Porous substrates will absorb the liquid binders so it is recommended to impregnate the surface with the appropriate thinner before using the adhesive. Thinner may be ordered by adding a "–T" to the product number (eg. 503–T).

2) Mix the adhesive thoroughly prior to use. Stir slowly to avoid air entrapment. Ceramabond™ 571 is a two component system with a mix ratio of 1 part liquid to 1.5 parts powder by weight.

3) Apply adhesive to each surface in a thin coat using a brush, spatula, spray gun or dispenser. Wet the surface thoroughly to ensure good adhesion.

4) The glue line thickness should be held between .002" and .010". Keep the glue line as uniform as possible to obtain good adhesion. Pressure should be applied and maintained until drying is complete. Do not repeatably squeeze assembly as this will cause air to be drawn into the glue line, thereby weakening the bond.

5) Immediately press the surfaces together maintaining a uniform glue line. Fixture if necessary. Wipe away excess before drying.

6) When applied as a coating, if repeat coats are necessary, spray substrate and allow it to air dry before applying the second coat. An oven dry at 200 °F is recommended before applying a third coat. This will avoid blistering during final cure. (See Section B).

B) CURING SCHEDULE:

All products require a heat cure. For Ceramabond™ 569 it is recommended but not required. Follow the schedule below.

1) Air set 1 to 4 hours depending upon the substrate size. The larger the part the longer the required air set.

2) Place part in oven at 200 °F for 1 to 4 hours. This will remove moisture gradually increasing the density and strength of the adhesive.

3) For maximum adhesion and moisture resistance raise temperature to 500 °F and hold for 1 hour. Note: This is a necessity for Ceramabond™ 503 to maintain integrity in humid envionments.

C) BONDING SUBSTRATES WITH DISSIMILAR COEFFICIENTS OF THERMAL EXPANSION

1) If materials have gross differences in CTE, then a graded adhesive line should be formed. First select an adhesive that best matches the CTE of each substrate. Coat each substrate with the best adhesive then use a third material with an intermediate CTE to bond the parts together.

2) Example: To bond nickel to silica, coat the nickel with Ceramabond™ 571 and the silica with the Ceramabond™ 618. Allow each substrate to air dry and cure at 200 °F. Apply Ceramabond™ 552 as the intermediate adhesive. Press parts firmly together and cure according to Section B.

D) SAFETY PRECAUTIONS:

1) Prolonged skin contact should be avoided due to possible irritation.

2) All products can be washed from skin with a mild soap and water in the uncured state.

3) If any material contacts eyes, flush continuously with water or neutralizing solutions; then consult a physician immediately.

Aremco Products, Inc. makes no warranty express or implied concerning the use of these products.
The user assumes all risks of use or handling whether or not in accordance with directions or suggestions, or used singly or in combination with other products.

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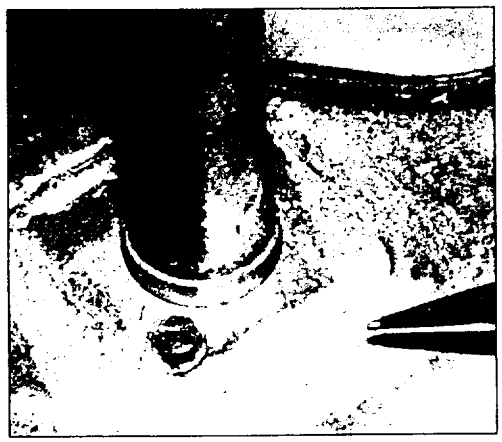
PYRO-PUTTY™ HIGH TEMPERATURE PUTTIES

Pyro-Putty™ materials are a family of thixotropic inorganic and organic paste-like materials, ideal for patching, coating, bonding, and sealing refractories, ceramics, glass and metals to withstand high temperatures and severe corrosive environments.

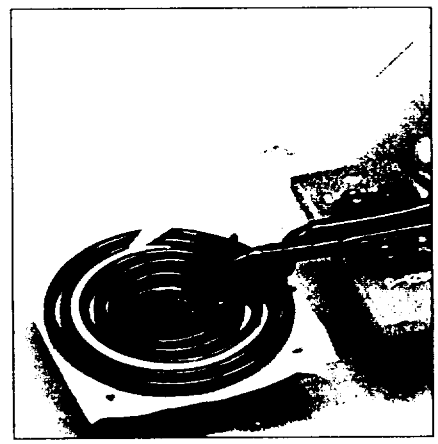
The **inorganic (ceramic base) group** of Pyro-Putties™ offer temperature resistance as high as 2500° F and include four basic materials filled with alumina, stainless steel, graphite and silica. They are applied as a thick paste with a caulking gun, spatula, or putty knife. After a simple cure, they are ready for high temperature use in applications such as coating or encapsulating copper induction heating coils, sealing furnace hatches, patching refractory walls and doors, repairing blow holes and voids in metal and ceramic molds, high temperature thread locking, coatings for wrap-around insulation, and repair of engine parts and exhaust manifolds.

The **organic group** of Pyro-Putties™ offer temperature resistance to 400° F combined with unique oxidation, solvent, acid and moisture resistance. Two basic materials are offered filled with alumina and stainless steel. Since they can be cured at room temperature, in-situ applications include repair of chemical process ducts, fume hoods, stacks, tank linings, gas scrubbers, waste lines, plating tanks, vats, sumps, racks, gas transmission lines, wall casings, reaction vats, ovens, electronic enclosures, marine structures and automotive parts.

Pyro-Putty 600™ shown being used to repair refractory brick in high temperature furnaces.



Pyro-Putty 653™ shown being used to repair a metal flange for a gas grill burner.



Pyro-Putty 677™ shown being used to encapsulate copper induction heating coils.

PYRO-PUTTY™ PROPERTIES

	INORGANIC GROUP				ORGANIC GROUP	
Product	**600**	**653**	**677**	**669**	**656**	**657**
Major Constituent	Alumina	Stainless Steel	Silica	Graphite	Alumina	Stainless Steel
Description	Formulated with high temp fibers, excellent for patching refractory brick, grouting wear tiles, and potting small sensors.	Metal-based high temp putty for patching corroded metal flange areas in boilers, burners, and engine manifolds. Extremely hard and durable upon cure.	Thixotropic formulation used for coating induction heating coils and potting small devices.	High temp putty for patching and bonding graphite fixtures, molds and components.	High strength, wear resistant, filled epoxy. Excellent for grouting high temp wear tiles and bonds extremely well to glass, ceramics, and metals.	High strength, wear resistant, filled epoxy. Bonds extremely well to glass, ceramics, and metals.
Max. Operating Temp. (°F)	2500	2400	2400	2500	400	400
Density (gm/cc)	2.7	1.9	2.5	1.8	1.8	1.65
Thermal Expansion (in/in/°F)	4.2×10^{-6}	7.0×10^{-6}	4.1×10^{-6}	4.5×10^{-6}	3.8×10^{-6}	3.5×10^{-6}
Volume Resistivity (ohm-cm)	1.0×10^{6}	1.4×10^{6}	1.0×10^{9}	1.0×10^{6}	1.2×10^{6}	1.2×10^{6}
Thermal Conductivity (BTU - in/hr-ft^2-°F)	45.8	78.9	20.0	160.9	3.82	4.0
Moisture Resistance	Good	Good	Excellent	Good	Excellent	Excellent
Oxidation Resistance	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Solvent Resistance	Excellent	Excellent	Excellent	Good	Excellent	Excellent
Thermal Shock Resistance	Very Good	Excellent	Excellent	Excellent	Excellent	Excellent
Acid Resistance	Fair	Fair	Good	Fair	Excellent	Excellent
# of Components	1	1	1	1	2	2
Visual Appearance	White	Grey	Off White	Black	Off White	Grey

See reverse side for application procedures. Refer to price list for pricing, terms and kit information. OA 12/92

AREMCO PRODUCTS, INC.
P.O. BOX 429 • OSSINING, NY 10562-0429
FAX: (914) 762-1663 • PHONE: (914) 762-0685

APPLICATION PROCEDURES
PYRO-PUTTY™ HIGH TEMPERATURE PUTTIES

A) SURFACE PREPARATION AND MIXING

1) Clean surface to be filled thoroughly, removing all dirt, oils and residues. Use acetone as a solvent if necessary.

2) Mix organic Pyro-Putty™ 656,657 in a ratio of 1:1 by weight, base to activator. Inorganic Pyro-Putty™ 600, 653, 677, 669 are single component compounds and require no catalyst. Mix all products thouroughly prior to use.

3) Apply with spatula, putty knife or caulking gun. Heavy sections should be coated with multiple thin layers to avoid bubbles and cracks. Dip copper induction coils into Pyro-Putty 677™ and remove excess putty from the center of the coil using a rod-shaped form. Cross-sections should not exceed 3/4".

4) Viscosity may be reduced using the appropriate chemical thinner. Thinner may be ordered by adding a "-T" to the product number (eg. 653-T).

B) CURE SCHEDULE

ORGANIC GROUP - Pyro-Putty™ 656, 657

Any of the following:
16 hours @ Room Temperature
3 hours @ 100°F
2 hours @ 150°F
1 hour @ 200°F

INORGANIC GROUP - Pyro-Putty™ 600, 653, 669

1) Air dry for 2 hours at room temperature. For large sections, allow to set at room temperature for 4 hours.
2) Heat cure at 200° F for 3 hours.

INORGANIC GROUP - Pyro-Putty™ 677

1) Material will begin to skin or harden on the copper coil in approximately 5 minutes.
2) Dry time can be accelerated by using a heat gun on low to medium heat (100 -150°F).
3) Cure the coil in an oven at 200° F for 2 hours for each 1/4" of thickness.

C) SAFETY PRECAUTIONS

1) Read Materials Safety Data Sheet carefully before use.
2) When using organic Pyro-Putty™ products, care should be taken to avoid skin contact. In the uncured state, MEK will remove resin followed by a soap and water wash.
3) Clean inorganic Pyro-Putties™, in the uncured state, with soap and water.
4) With all products, if material contacts eyes, flush continuously with water or neutralizing solution. Contact physician immediately.

Aremco Products, Inc. makes no warranty express or implied concerning the use of these products. The user assumes all risk of use or handling whether or not in accordance with directions or suggestions, or used singly or in combination with other products.

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APPENDIX C : VACUUM CHAMBER DRAWINGS

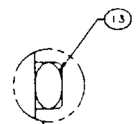
NOTES:

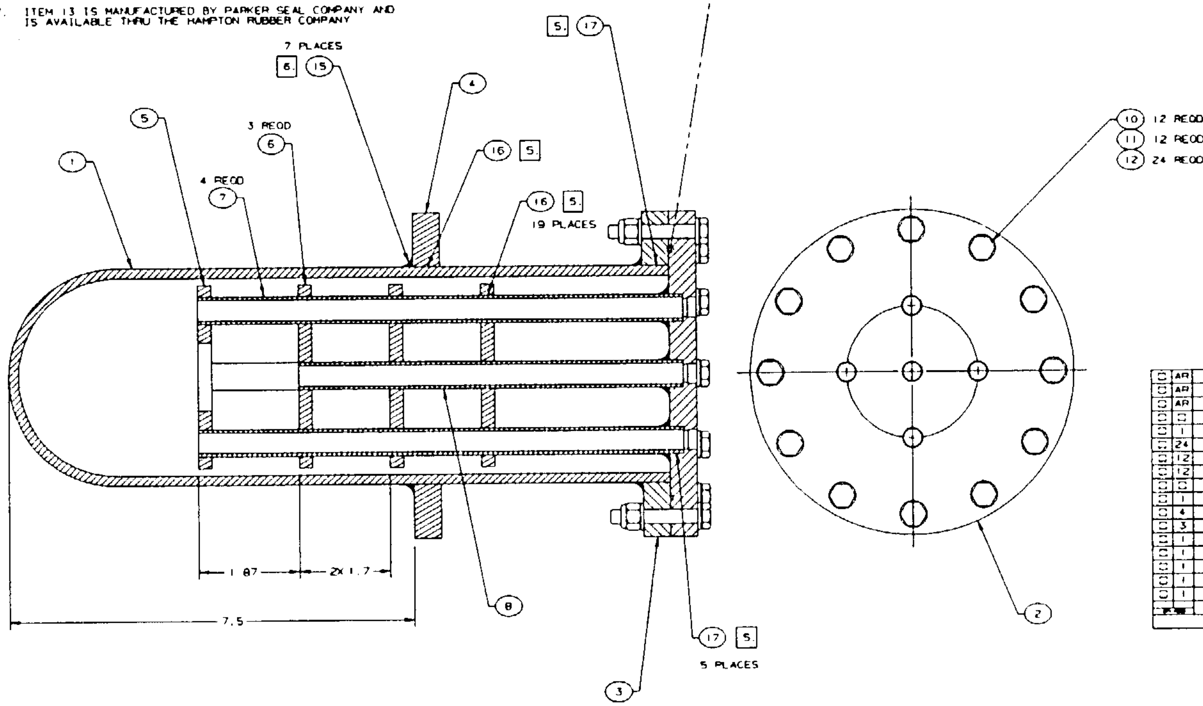
1. APPLICABLE STANDARDS/SPECIFICATIONS ANSI Y14.5M-1982, DIMENSIONS AND TOLERANCES
2. REMOVE ALL BURRS AND SHARP EDGES
3. SURFACE ROUGHNESS SHALL BE 125 RMS OR BETTER
4. ITEMS 15 THRU 17 CAN BE PURCHASED FROM AREMCO MATERIALS, PHONE (914) 762-0685

5. CLEAN MATING PARTS, APPLY ADHESIVE, ALLOW TO CURE AND FIRE TO SET ADHESIVE PER THE MANUFACTURERS INSTRUCTIONS

6. CLEAN MATING PARTS, APPLY PUTTY, ALLOW TO CURE AND HEAT PER THE MANUFACTURES INSTRUCTIONS

7. ITEM 13 IS MANUFACTURED BY PARKER SEAL COMPANY AND IS AVAILABLE THRU THE HAMPTON RUBBER COMPANY





AR		CERMABOND 571	ADHESIVE, HIGH TEMP	MAGNESIA ADHESIVE	17
AR		CERMABOND 503	ADHESIVE, HIGH TEMP	ALUMINA ADHESIVE	16
AR		PYRO PUTTY 600	PUTTY, HIGH TEMP	ALUMINA PUTTY	15
					14
1		2-047 V070	SEAL, O-RING	VITON	13
24		AN960C416	WASHER, FLAT	300 CRES	12
12		MS35649-2254	NUT, PLAIN, HEXAGON	300 CRES	11
12		MS35307-312	SCREW, HEXAGON HD	304 CRES	10
					9
1		MOP008-3	OXYGEN EXIT TUBE	ALUMINA	8
4		MOP008-1	GAS & ACCESS TUBE	ALUMINA	7
3		MOP007-1	RADIATION BAFFLE	ALUMINA	6
1		MOP006-1	END CAP	ALUMINA	5
1		MOP005-1	SUPPORT RING	ALUMINA	4
1		MOP004-1	UPPER RING	347 CRES	3
1		MOP003-1	CAP	347 CRES	2
1		MOP002-1	BODY	ALUMINA	1

PARTS LIST

DISTRIBUTION STATEMENT A.
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DEPARTMENT OF MECHANICAL ENGINEERING AND MECHANICS
OLD DOMINION UNIVERSITY
NORFOLK, VIRGINIA

ASSEMBLY, VACUUM CHAMBER, NEW FURNACE PROJECT, MARS OXYGEN PRODUCTION

DWG NO MOP001 SH 1 REV

REVISIONS

ZONE | REV | DESCRIPTION | DATE | APPROVED

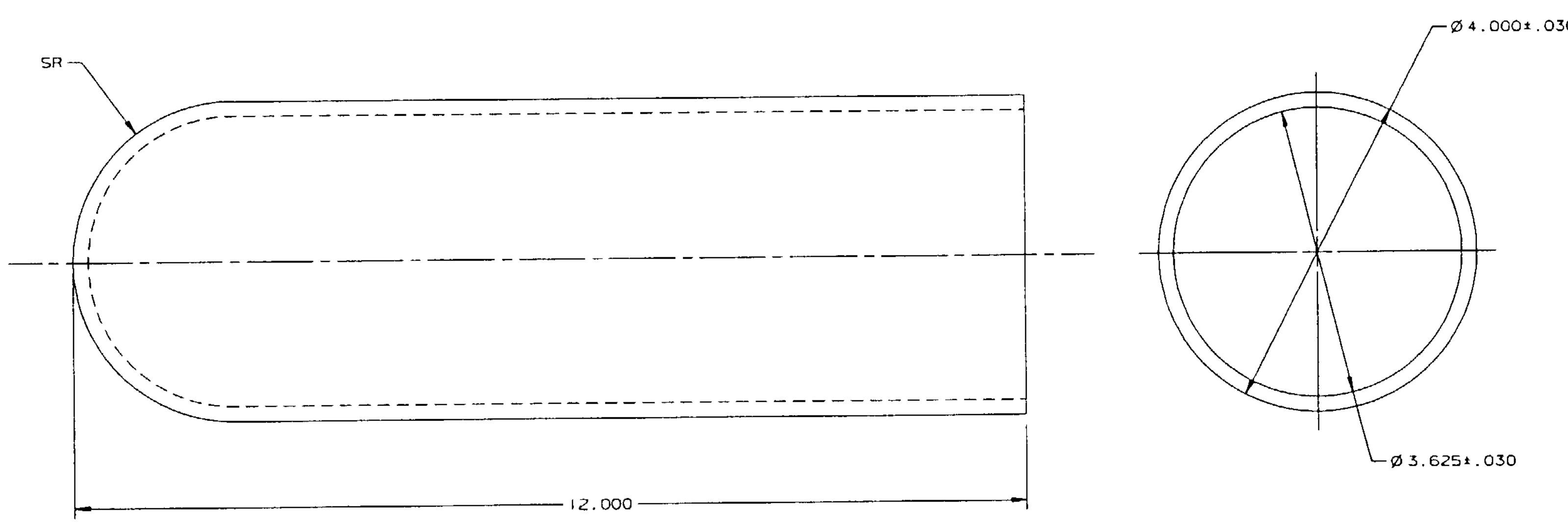
-1 2 2 FINAL
NEXT ASSY USED ON
APPLICATION

K W DAVIS 93-03-19

SIZE D DWG NO MOP001
SCALE 1/1 SHEET 1 OF 1

NOTES:

1. APPLICABLE STANDARDS/SPECIFICATIONS ANSI Y14.5M-1982. DIMENSIONS AND TOLERANCES
2. REMOVE ALL BURRS AND SHARP EDGES
3. SURFACE ROUGHNESS SHALL BE 125 RMS OR BETTER
4. MATERIAL IS ALUMINA, 99.8% PURE AND MUST BE GAS TIGHT. IT IS AVAILABLE AS CAST TUBING FROM COORS CERAMIC COMPANY, GOLDEN CO PHONE (303) 277-4043



REVISIONS

ZONE	REV	DESCRIPTION	DATE	APPROVED

PARTS LIST

QTY REQD	CAGE CODE	DASH	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION	ITEM NO.
			-1	BODY	SEE NOTE 4.	1

DISTRIBUTION STATEMENT A.
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DEPARTMENT OF MECHANICAL ENGINEERING AND MECHANICS
OLD DOMINION UNIVERSITY
NORFOLK, VIRGINIA 23529-0247

DRAWN: K W DAVIS 93-03-17

TITLE: BODY, VACUUM CHAMBER, NEW FURNACE PROJECT, MARS OXYGEN PRODUCTION

SIZE: C DWG. NO. MOP002

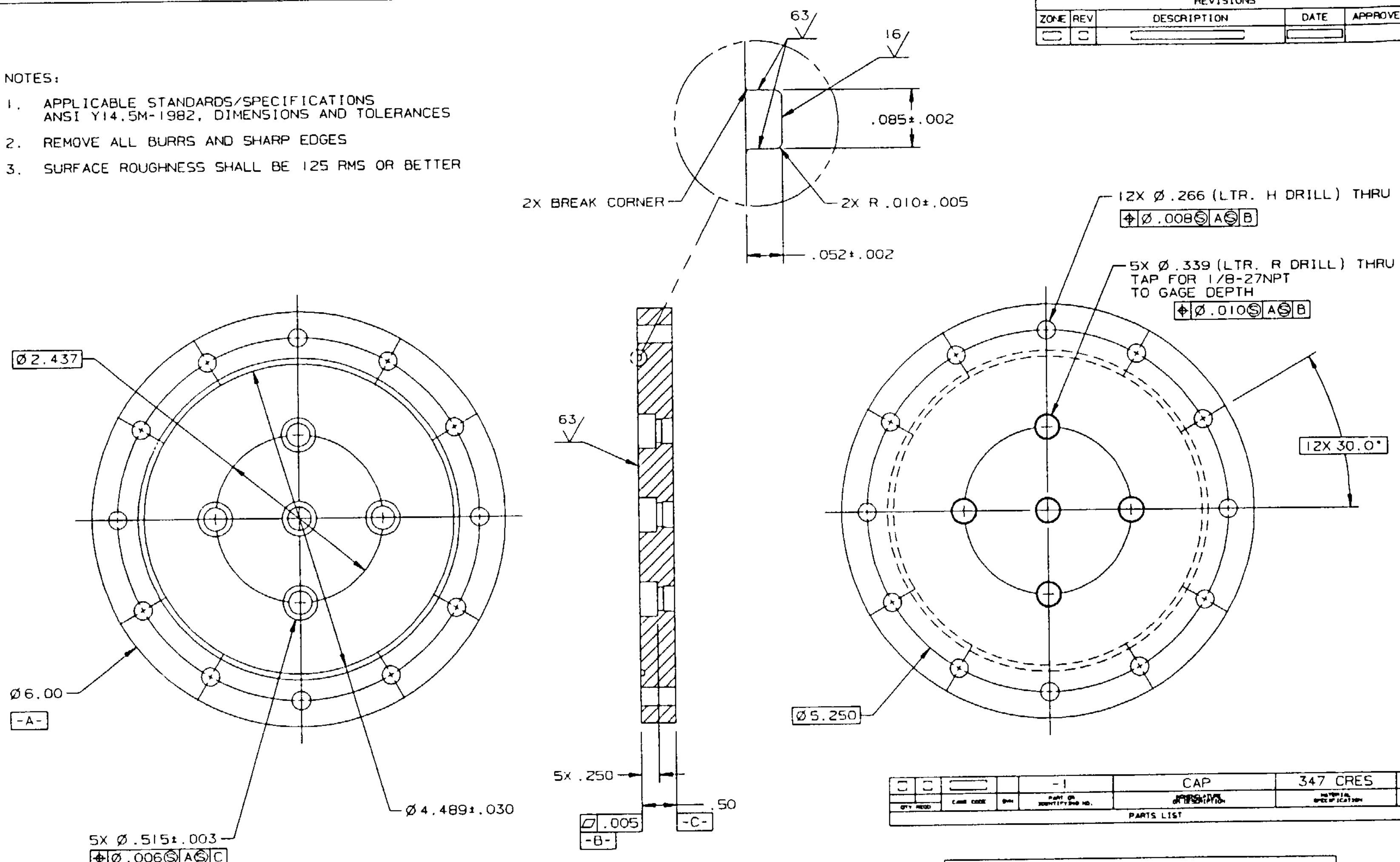
SCALE 1/1 SHEET 1 OF 1

NEXT ASSY: MOP001

DWG. NO. MOP002

NOTES:

1. APPLICABLE STANDARDS/SPECIFICATIONS ANSI Y14.5M-1982, DIMENSIONS AND TOLERANCES
2. REMOVE ALL BURRS AND SHARP EDGES
3. SURFACE ROUGHNESS SHALL BE 125 RMS OR BETTER



QTY REQD	CAGE CODE		PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION	ITEM NO
			-1	CAP	347 CRES	1

PARTS LIST

DISTRIBUTION STATEMENT A.
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ZONE	REV	DESCRIPTION	DATE	APPROVED

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TITLE CAP, VACUUM CHAMBER, NEW FURNACE PROJECT, MARS OXYGEN PRODUCTION

DRAWN K W DAVIS 93-03-16

SIZE C DWG. NO. MOP003

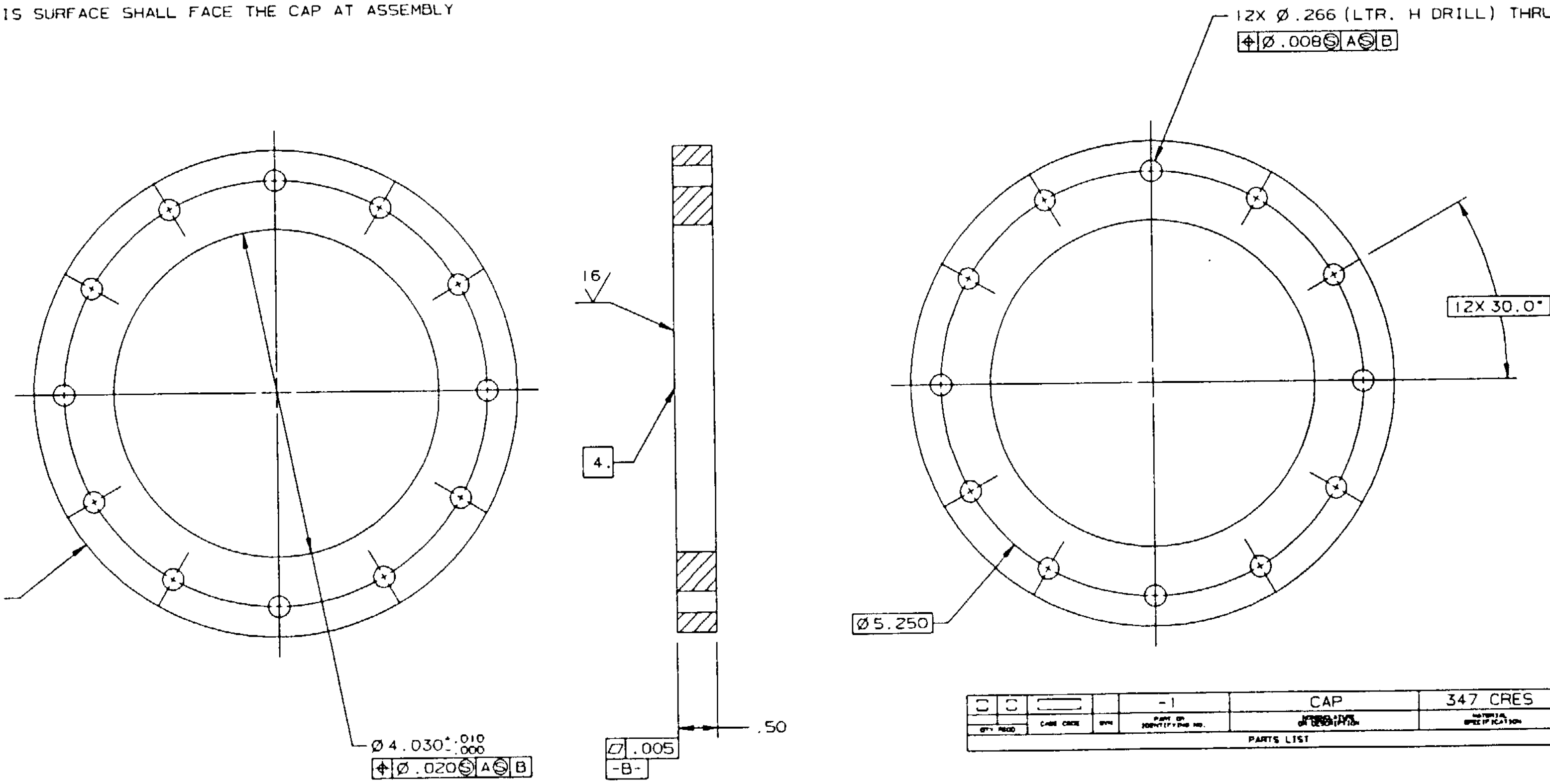
SCALE 1/1 SHEET 1 OF 1

-1 MOP001

MOP003

NOTES:

1. APPLICABLE STANDARDS/SPECIFICATIONS ANSI Y14.5M-1982, DIMENSIONS AND TOLERANCES
2. REMOVE ALL BURRS AND SHARP EDGES
3. SURFACE ROUGHNESS SHALL BE 125 RMS OR BETTER
4. THIS SURFACE SHALL FACE THE CAP AT ASSEMBLY



REVISIONS				
ZONE	REV	DESCRIPTION	DATE	APPROVED

PARTS LIST

QTY REQD		CAGE CODE	SYM	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION	ITEM NO.
				-1	CAP	347 CRES	1

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TITLE: UPPER RING, VACUUM CHAMBER, NEW FURNACE PROJECT, MARS OXYGEN PRODUCTION

DRAWN: E W DAVIS 93-03-16

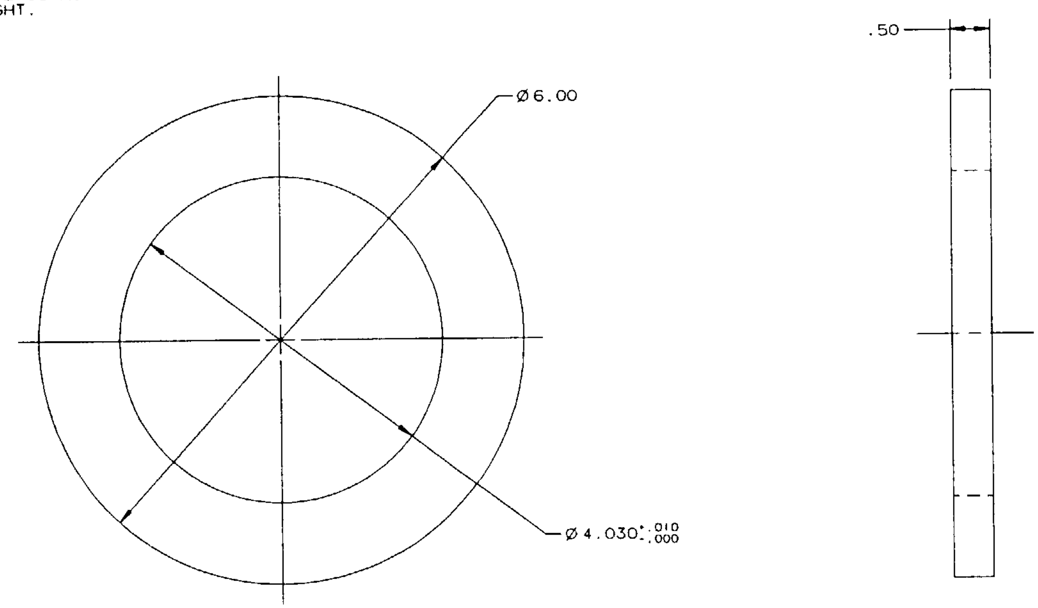
SIZE: C | DWG. NO. MOP004 | SCALE 1/1 | SHEET 1 OF 1

PART DASH NO.	NEXT ASSY	FINAL	NEXT ASSY	USED ON
-1	1	1	MOP001	

DWG. NO. MOP004

NOTES:

1. APPLICABLE STANDARDS/SPECIFICATIONS ANSI Y14.5M-1982, DIMENSIONS AND TOLERANCES
2. REMOVE ALL BURRS AND SHARP EDGES
3. SURFACE ROUGHNESS SHALL BE 125 RMS OR BETTER
4. MATERIAL IS HIGH PURITY ALUMINA. IT MUST BE GAS TIGHT.



QTY REQD	CAGE CODE	SYM	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION	ITEM NO.
			-1	SUPPORT RING	SEE NOTE 4.	1

PARTS LIST

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TITLE SUPPORT RING, VACUUM CHAMBER, NEW FURNACE PROJECT, MARS OXYGEN PRODUCTION

DRAWN K W DAVIS 93-03-17

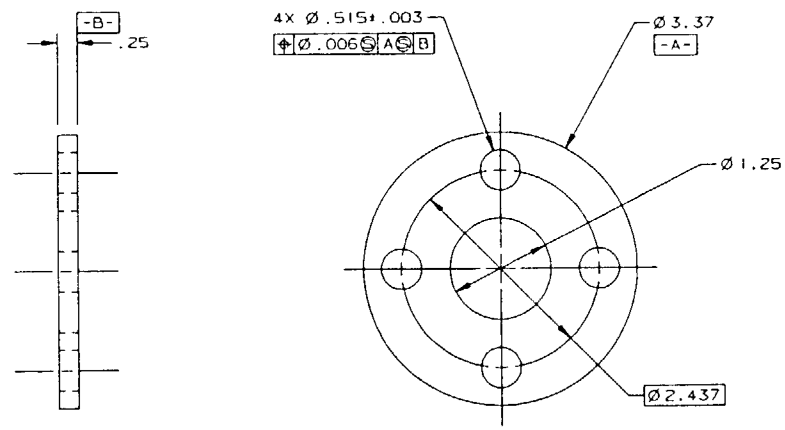
SIZE C   DWG. NO. MOP005   SCALE 1/1   SHEET 1 OF 1

PART DASH NO.	NEXT	FINAL	NEXT ASSY	USED ON
-1	1	1	MOP001	

APPLICATION

NOTES:

1. APPLICABLE STANDARDS/SPECIFICATIONS
   ANSI Y14.5M-1982, DIMENSIONS AND TOLERANCES
2. REMOVE ALL BURRS AND SHARP EDGES
3. SURFACE ROUGHNESS SHALL BE 125 RMS OR BETTER
4. MATERIAL IS HIGH PURITY ALUMINA. IT MUST BE GAS TIGHT.



ZONE	REV	DESCRIPTION	DATE	APPROVED

(REVISIONS)

QTY REQD	CAGE CODE	DWG	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION	ITEM NO.
			-1	END CAP	SEE NOTE 4.	1

PARTS LIST

DISTRIBUTION STATEMENT A.
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DRAWN: K W DAVIS — 93-03-18

NEXT ASSY: MOP001

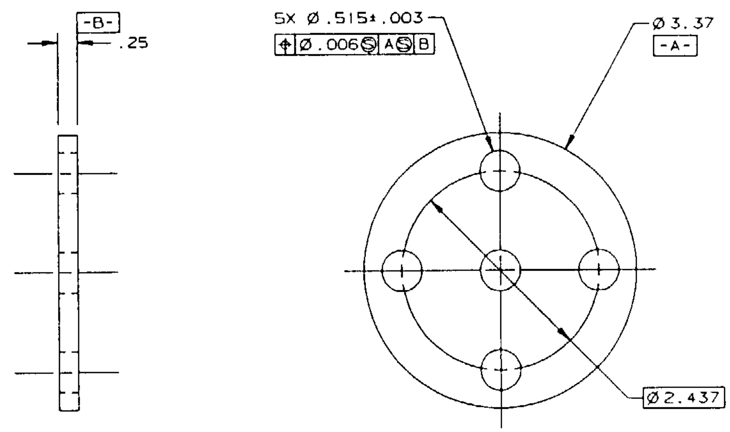
DEPARTMENT OF MECHANICAL ENGINEERING AND MECHANICS
OLD DOMINION UNIVERSITY
NORFOLK, VIRGINIA 23529-0247

TITLE: END CAP, VACUUM CHAMBER, NEW FURNACE PROJECT, MARS OXYGEN PRODUCTION

SIZE: C — DWG. NO. MOP006 — SCALE 1/1 — SHEET 1 OF 1

NOTES:

1. APPLICABLE STANDARDS/SPECIFICATIONS ANSI Y14.5M-1982, DIMENSIONS AND TOLERANCES
2. REMOVE ALL BURRS AND SHARP EDGES
3. SURFACE ROUGHNESS SHALL BE 125 RMS OR BETTER
4. MATERIAL IS HIGH PURITY ALUMINA. IT MUST BE GAS TIGHT.



REVISIONS				
ZONE	REV	DESCRIPTION	DATE	APPROVED

PARTS LIST

QTY REQD		CAGE CODE		PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION	ITEM NO
				-1	RADIATION BAFFLE	SEE NOTE 4.	1

DISTRIBUTION STATEMENT A.
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PART DASH NO.	QTY REQD NEXT ASSY	QTY REQD FINAL ASSY	NEXT ASSY	USED ON
-1	3	3	MOP001	

APPLICATION

DEPARTMENT OF MECHANICAL ENGINEERING AND MECHANICS
OLD DOMINION UNIVERSITY
NORFOLK, VIRGINIA 23529-0247

TITLE RADIATION BAFFLE, VACUUM CHAMBER, NEW FURNACE PROJECT, MARS OXYGEN PRODUCTION

DRAWN E W DAVIS 93-03-18

SIZE C DWG NO. MOP007 SCALE 1/1 SHEET 1 OF 1

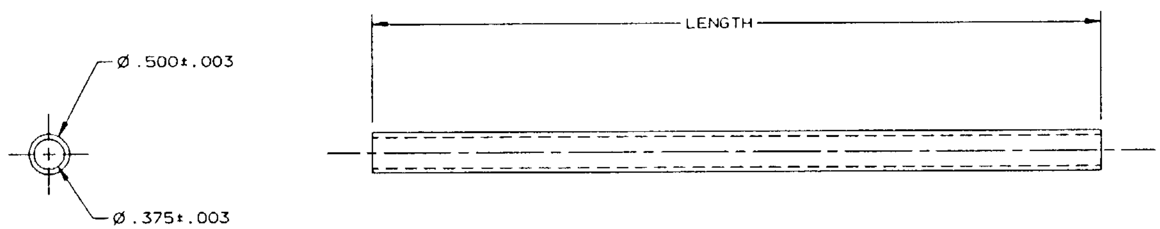
DWG NO. MOP007 REV -

REVISIONS

ZONE	REV	DESCRIPTION	DATE	APPROVED

NOTES:

1. APPLICABLE STANDARDS/SPECIFICATIONS
   ANSI Y14.5M-1982, DIMENSIONS AND TOLERANCES
2. REMOVE ALL BURRS AND SHARP EDGES
3. SURFACE ROUGHNESS SHALL BE 125 RMS OR BETTER
4. MATERIAL IS ALUMINA, 99.8% PURE AND MUST BE GAS TIGHT. IT IS AVAILABLE AS EXTRUDED TUBING FROM COORS CERAMIC COMPANY, GOLDEN CO PHONE (303) 277-4043



DASH NO	LENGTH
-1	9.00
-3	7.13

PARTS LIST

QTY REQD		CAGE CODE		PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION	ITEM NO
				-3	OXYGEN EXIT TUBE	SEE NOTE 4.	1
				-1	GAS & ACCESS TUBE	SEE NOTE 4.	1

DISTRIBUTION STATEMENT A.
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PART DASH NO.	NEXT	FINAL	NEXT ASSY	USED ON
-3	1	1	MOP001	
-1	4	4	MOP001	

APPLICATION

DRAWN: E W DAVIS — 93-03-18

DEPARTMENT OF MECHANICAL ENGINEERING AND MECHANICS
OLD DOMINION UNIVERSITY
NORFOLK, VIRGINIA 23529-0247

TITLE: TUBE, VACUUM CHAMBER, NEW FURNACE PROJECT, MARS OXYGEN PRODUCTION

SIZE: C — DWG. NO. MOP008

SCALE 1/1 — SHEET 1 OF 1

DWG. NO. MOP008